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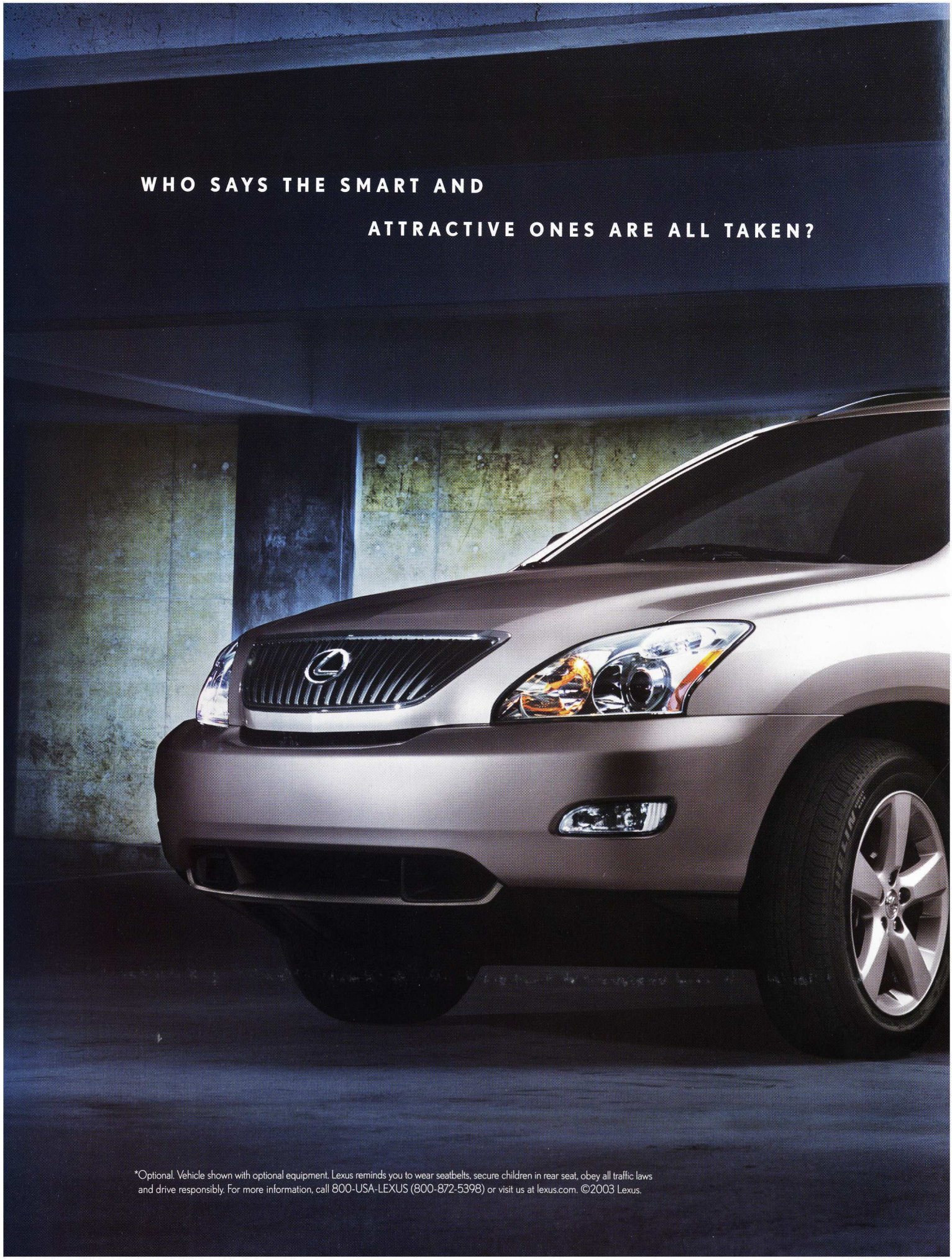
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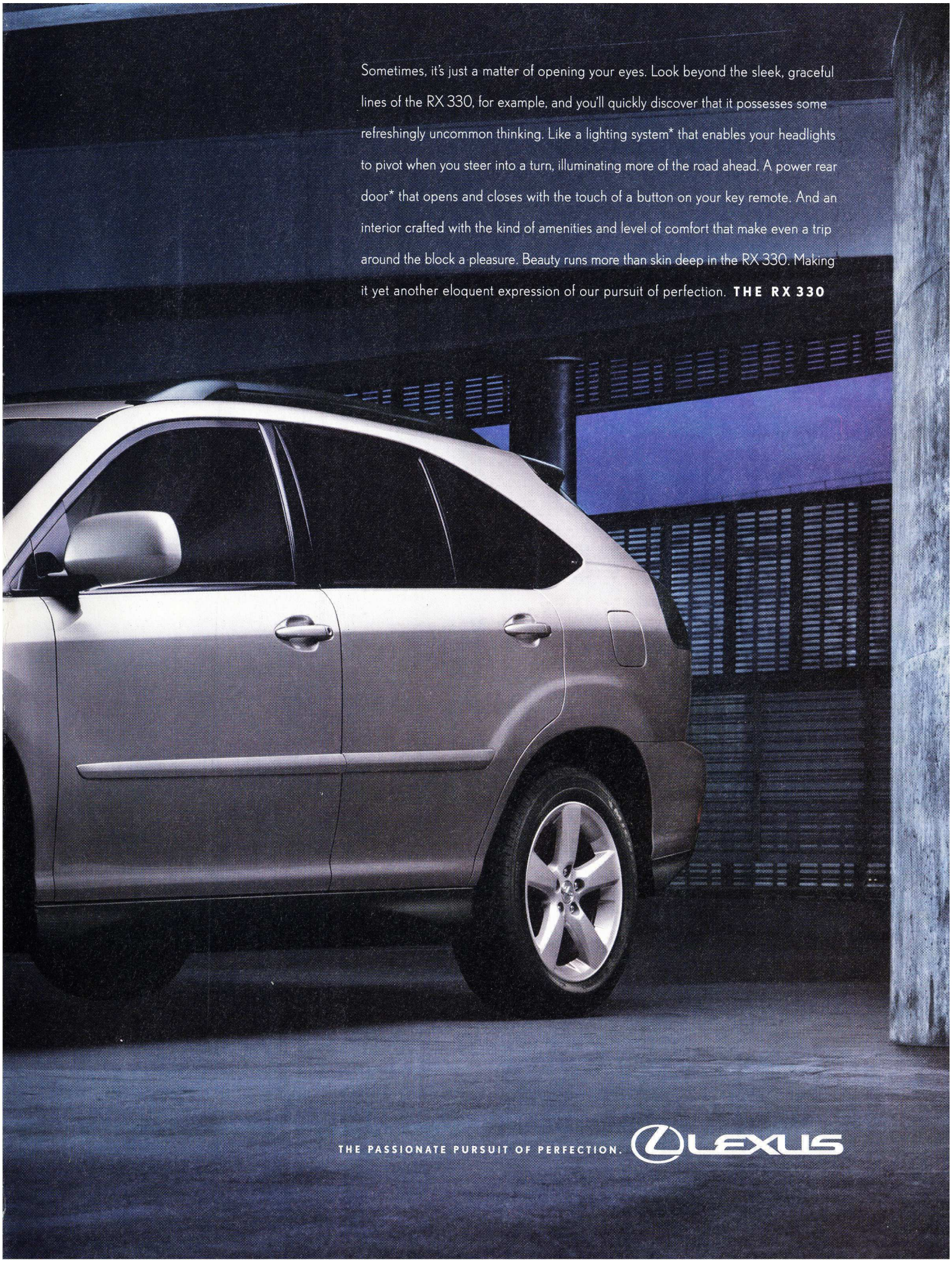
Sometimes, it's just a matter of opening your eyes. Look beyond the sleek, graceful lines of the RX 330, for example, and you'll quickly discover that it possesses some refreshingly uncommon thinking. Like a lighting system* that enables your headlights to pivot when you steer into a turn, illuminating more of the road ahead. A power rear door* that opens and closes with the touch of a button on your key remote. And an interior crafted with the kind of amenities and level of comfort that make even a trip around the block a pleasure. Beauty runs more than skin deep in the RX 330. Making it yet another eloquent expression of our pursuit of perfection. THE RX 330
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Cover photograph by Holly Lindem

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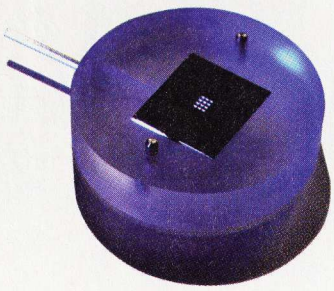
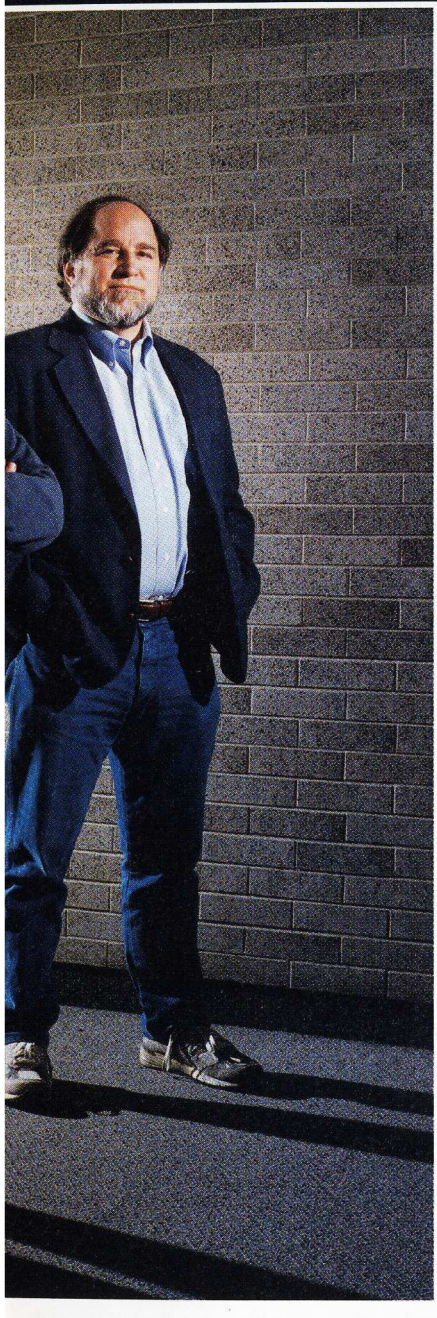


Technology Review
Volume 106, Number 10
December 2003/January 2004

"One year ago, it was, 'Will they pay?' Now it's, 'How will they pay?'" —*Ian Price, p. 32*



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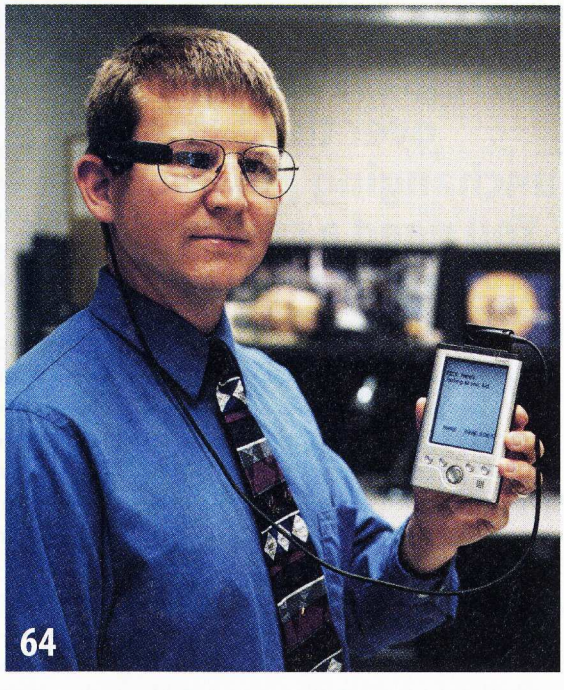

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▪ Expanded R&D Scorecard ▪ TechnologyReview.com blog, featuring technology commentary by MIT professors Rodney Brooks and Henry Jenkins and writers Simson Garfinkel and David Kushner ▪ And more...

Other People's Progress

DURING THE FIRST HALF OF THE 20TH CENTURY, FEW figures spoke more authoritatively on national technological and economic matters than Charles Kettering. The "Boss" cofounded the Dayton Engineering Laboratories Company (Delco), where he invented the automotive self-starter and the Delco Light generator that powered hundreds of thousands of farms. Then, lured to Detroit by General Motors head Alfred P. Sloan Jr., he took the reins of GM's research, which pioneered four-wheel brakes and ethyl fuel. Kettering believed passionately in the power of research and development, and he had this to say in a 1929 speech to the U.S. Chamber of Commerce:

"I am not pleading with you to make changes. I am telling you you have got to make them—not because I say so, but because old Father Time will take care of you if you don't change. Advancing waves of other people's progress sweep over the unchanging man and wash him out. Consequently, you need to organize a department of systematic change-making."

Advancing waves of other people's progress sweep over the unchanging person. You need a system of change-making.

Change-making. Few words better describe the essence of what *Technology Review* seeks to examine in every issue—whether the change agents come from big companies, startups, or university or government labs. This month, we're bringing you a special view of what goes on in the first category: cutting-edge technological development at large corporations. Our annual R&D Scorecard *(p. 59)* shows at a glance which organizations are most emphatically embracing the effort to create change—and which are cutting back, risking being swept away by other people's progress.

What does it mean for the future, for instance, that in computer hardware only a few companies, among them IBM, Canon, and Ricoh, seem to be maintaining their previous levels of funding, when inflation is factored in (Hewlett-Packard's huge 53 percent rise is due to its merger with Compaq; otherwise spending is roughly flat)? Or that in the pharmaceutical and medicine sector, Pfizer's R&D spending showed a healthy 6.8 percent gain to $5.2 billion (it will be more than $7 billion next year when Pfizer's merger with Pharmacia shows up), widening the gap between it and its competitors?

These are crucial questions. As is made clear in many studies, most notably Alfred D. Chandler Jr.'s *Scale and Scope*, organizations that don't make a significant commitment to R&D do not survive over the long haul—no matter how dominant they are at a given moment. The waves of other people's progress are simply too powerful, too relentless, to be met with halfhearted efforts.

But numbers tell only part of the story. That's why we have complemented the R&D Scorecard with two articles designed to give you a richer perspective on what's happening in the innovation machines of both large companies and the U.S. as a whole. First, we scoured corporate labs around the globe to find the most interesting and vital projects about to be commercialized; contributing editor Erika Jonietz profiles the most compelling in "Seven Hot Projects" *(p. 52)*. From General Electric's handheld ultrasound device, to IBM's speech-to-speech language translator, to Microsoft's latest tool for fighting spam, these efforts testify to the problem-solving virtuosity of large companies willing to put their minds to change-making.

That's the fun part. Alongside the hot projects comes a fascinating article by Kenan Sahin, a megasuccessful entrepreneur who sold his software-systems company to Lucent Technologies a few years ago. After working in management at Bell Labs, Sahin founded an independent research firm, Tiax. In "Our Innovation Backlog" *(p. 56)*, Sahin takes a contrarian view of our doldrums economy. It's not that innovation has slowed, he says; in fact, the engines of innovation are churning away at ever faster rates. Rather, it's that the United States is slipping in its ability to commercialize those innovations. "Unquestionably, the solutions to many current problems, the treatments for many illnesses, and the pathways to new business areas have already been invented, but are waiting on the sidelines," he writes. Sahin, it may not surprise you, has some interesting ideas on what can be done to bring those neglected technologies to market—starting from his observation that innovators are like ants.

Our R&D special report presents just a few of the change-making efforts documented in this month's issue. So be sure to dive right in—and don't be afraid of the waves. **Robert Buderi**

JOE CHUNG'S NEW COLUMN

This month marks the debut of Joe Chung's bimonthly column bringing you an angel investor's view of emerging companies. In his inaugural column *(p. 26)*, Chung looks at Ovation Products, which seeks to bring cheap, affordable, clean water to the world.

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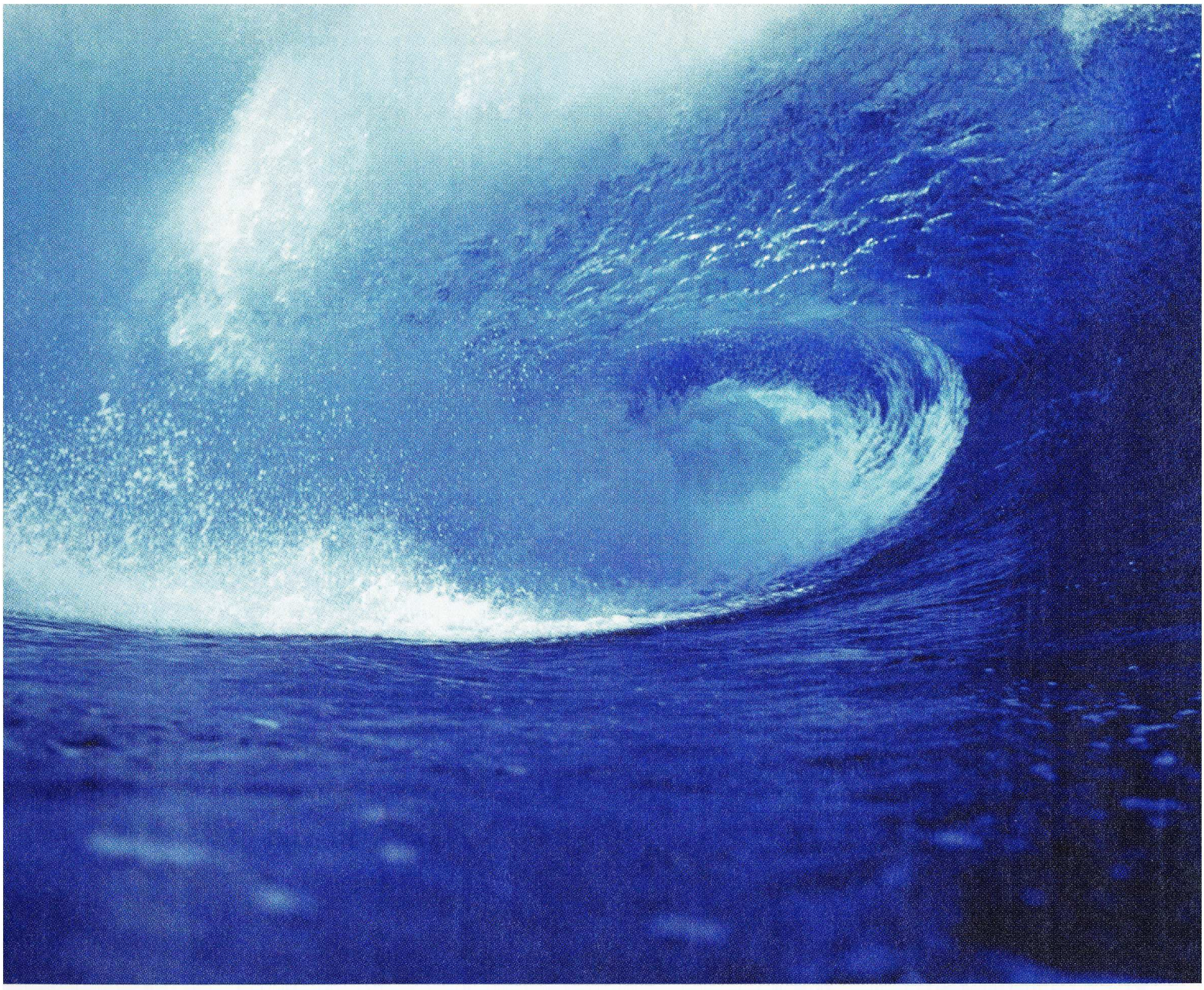

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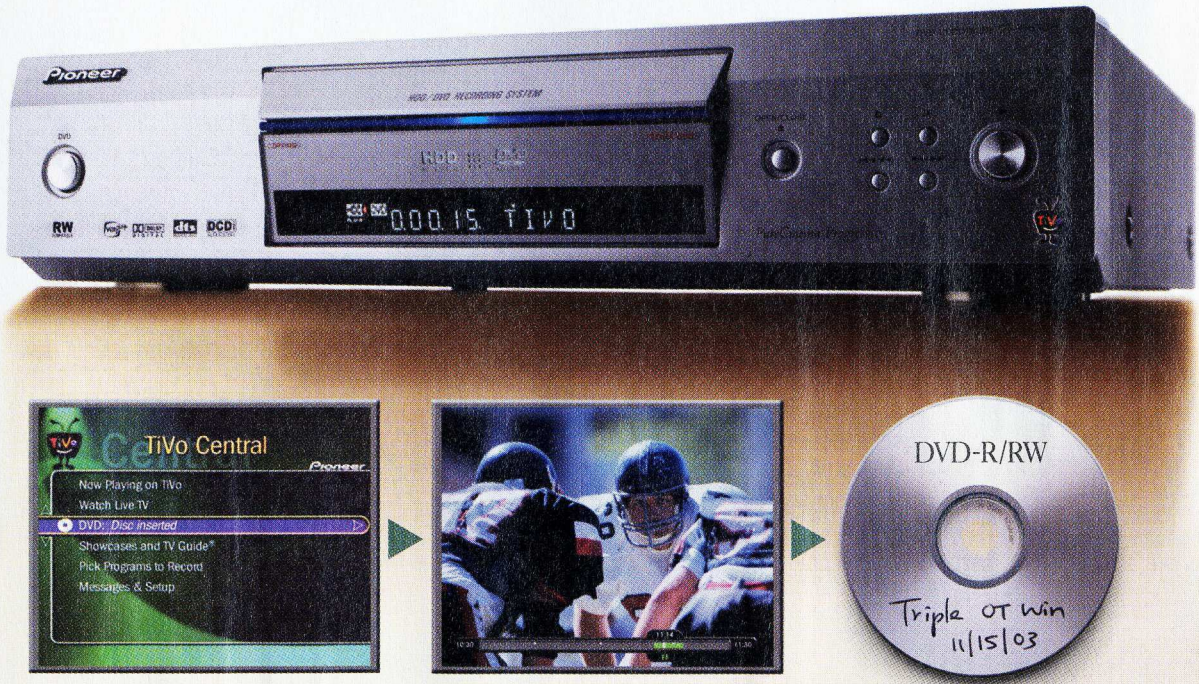

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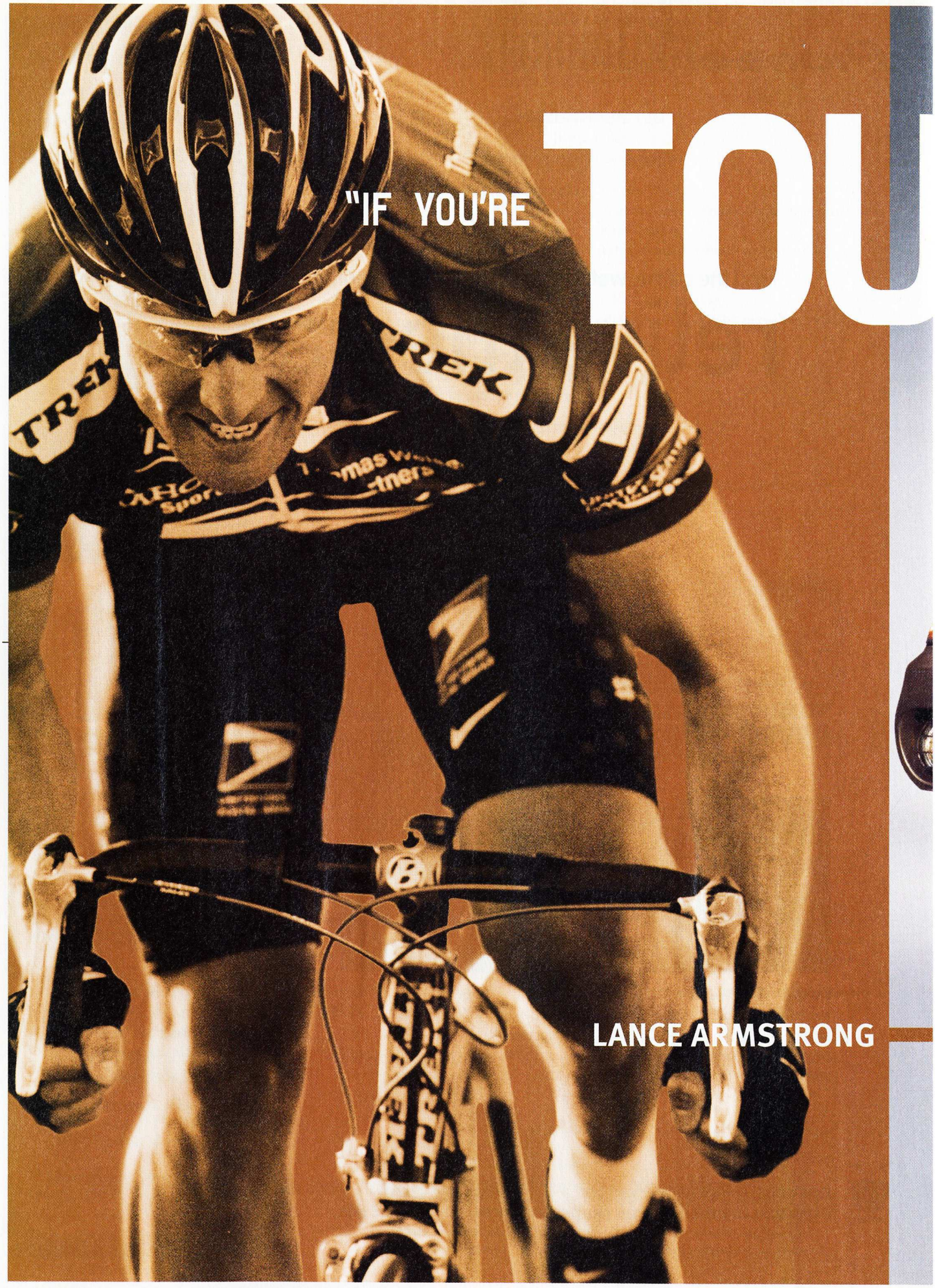
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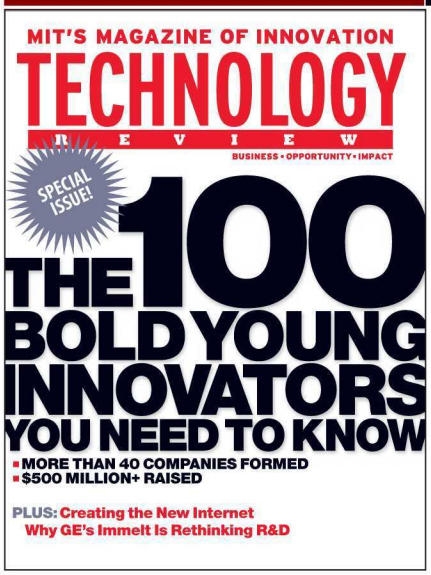

BOLD GEEZER INNOVATORS

I RAVED OVER YOUR PIECE "THE 100 Bold Young Innovators You Need to Know" (*TR* October 2003). The ideas are first-rate, the innovators indeed bold and, I have to say it, stunningly attractive. However, I just looked in the mirror, took a look around my workplace, conjured up the images of some of my colleagues, and now have a request for you: would you also please put together a piece on "The Boldest Old Geezer Innovators"?

Ashley R. Heath
The Woodlands, TX

THE TECHNOLOGY DEATH LIST

WHILE HEARTILY AGREEING WITH most of Bruce Sterling's "Ten Technologies That Deserve to Die" (*TR* October 2003), we question his wish to do away with manned spaceflight. Something in the human spirit needs hands-on effort—not in every individual being, but in the collective soul. If we cannot explore in person, the space program will die even more surely and swiftly than it appears to be dying now. Without the hope of someday colonizing other points in space or at least studying free-fall environments, the whole effort will have lost its point. True, going to the moon, leaving a flag, and retreating makes little sense, but the trouble was in the failure to follow up.

Clifton A. Hoyt and Phyllis Ann Karr
Barnes, WI

I KNOW STERLING'S ARTICLE WAS supposed to be humorous, but too many people think those points were realistic. I have grown fond of the lifestyle that permits me to travel, to find fresh nonlocal fruit and vegetables in the market year round, to have a refrigerator so I don't have to go to the store every day. If it weren't for our highly effective agricultural segment (those disgusting internal-combustion tractors) and the means to distribute produce throughout our land (those hateful tractor-trailers), we would be nothing but a huge Third World nation, with each person eking out her own living from the local soil.

John Peters
Fremont, MI

ONE TECHNOLOGY THAT CERTAINLY deserves to be on your list is genetic engineering. Responding to no real discernible human need, genetically engineered crops and genetically modified foods are being foisted on the public in a stealth fashion (no labeling) with no consumer benefit and taking advantage of cross-contamination to eliminate organic and good conventional produce. The medical technologies are largely hype. The existing products are largely designed to make lots of profits while catering to human conditions that have become "medicalized," such as shortness, for which human growth hormone is being sold.

Phil Bereano
University of Washington
Seattle, WA

"I now have a request for you: would you also please put together a piece on 'The Boldest Old Geezer Innovators'?"

INSTEAD OF DOING AWAY WITH manned spaceflight and prisons, why don't we just combine the two into one simple solution? "What are you out for?"

Larry D. Helwig
Las Vegas, NV

INTERNET ALREADY REBORN

THE OCTOBER 2003 ISSUE INCLUDED a description of Ian Clarke as one of the "100 Bold Young Innovators." But an article in the same issue, "The Internet Reborn," by Wade Roush, made no mention of Clarke's contributions. Clarke's Freenet project, running smoothly on thousands of volunteer nodes, has many of the features mentioned in Roush's piece. Freenet also uses unique encryption technology that provides secrecy, authenticity and anonymity—an increasingly scarce commodity on the Internet.

Adam C. Powell IV
MIT
Cambridge, MA

CLEAN-COAL CONTRADICTION

REGARDLESS OF HOW COMBUSTION products are filtered, coal can't be oxidized without producing carbon dioxide ("Cleaning Up Coal," *TR* October 2003). Contrary to your article's assertion, there's no way to pipe cubic kilometers of carbon dioxide off to underground repositories. The metal-ceramic filter described may have some useful applications, but coal gasification isn't one of them. Clearer minds seem to prevail elsewhere in the same issue: in his list of "Ten Technologies That Deserve to Die," science fiction writer Bruce Sterling ranks coal-based power at number two.

John Schaefer
Arcata, CA

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CORRECTION: The company developing brain glutamate microsensors ("Mind Readers," *TR* October 2003) should have been identified as Quanteon.

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DRIVERS: PAY ATTENTION

MORE THAN A QUARTER OF CAR CRASHES CAN BE BLAMED ON DRIVERS WHO simply aren't paying attention. So while some experimental car-safety systems look out for approaching obstacles, tailgaters, and other hazards, a team of researchers at the University of California, San Diego, is developing a tool that keeps an eye on the driver to make sure his or her eyes are on the road. Led by electrical engineer Mohan Trivedi, the team has come up with a single-camera system that simultaneously tracks both the driver's head and the road. Mounted on the dashboard, side mirror, or sunroof, the camera is coupled with a dome-shaped mirror that gives a 360-degree view of what's going on inside and outside the car. Software running on a computer in the trunk analyzes the camera image to estimate what the driver is looking at in real time, based on the tilt of his or her head and face; if the system determines the driver is not paying attention to an imminent hazard, it sounds an alarm in the car. The researchers have so far installed the prototype system in two experimental vehicles and are now testing it to see if it can detect where a car is in relation to lane markers and alert the driver if the car is unintentionally drifting out of the lane. They have recently filed a patent on the technology.

A camera sees both driver and road.

GAMES ON THE GRID

Researchers at IBM's Almaden Research Center in San Jose, CA, have created prototype software that lets up to 500 users participate in processor-intensive "first-person shooter" games such as Quake II. In the past, players running such games on their personal computers could join only a handful of competitors via the Internet. But the IBM software parcels out responsibility for simulating different zones of Quake's dungeonlike world to remote linked or "grid" computers. The system mediates between the users' computers and the grid computers, handing over a character's direction, speed, and other data when it steps from one zone to another. James Kaufman, the project's lead researcher, says IBM is "talking to customers" in the online-gaming market about how the system could help them create bigger, busier fantasy worlds.

A sensor-laden robot monitors the forest canopy.

TREE BOT

IT'S A BIRD, IT'S A PLANE, IT'S...A ROBOT IN THE TREES? AT THE WIND RIVER Canopy Crane Research Facility in Carson, WA, scientists have deployed a briefcase-size robot that rolls along a 50-meter-high cable strung between trees. Built by electrical engineer William Kaiser's team at the University of California, Los Angeles, the robot comes equipped with environmental sensors, a still camera, a processor, batteries, solar cells, and a wireless link to the Internet. Programmed to patrol the forest canopy, the high-rolling robot maps changes in temperature, humidity, and sunlight. The researchers plan that in the future the device will also monitor carbon dioxide concentration, while documenting the growth of individual leaves and branches—measurements that were previously hard to make. The National Science Foundation is footing the bill, to pinpoint how much carbon and heat the trees absorb from the atmosphere; this could help researchers predict the climatic effects of harvesting and deforestation. Deployments are planned in three other forests by springtime, says Kaiser.

GREAT BALLS OF FIRE

WHEN YOU SEE FIRE IN MOVIES, IT'S usually real and dangerous. Computer animations are rarely used, because they neglect the intricate physics of fire—and it shows. Now computer scientists Ron Fedkiw of Stanford University and Henrik Jensen of the University of California, San Diego, have developed software that creates realistic animations of fire. Set initial conditions, like temperature, type of fuel, and surface shape, and the computer does the rest. The software solves equations that describe swirling fluids, expanding gases, and vaporized fuel, and renders effects like smoke, soot, and objects igniting. It takes about five minutes to generate each frame, but filmmakers and special-effects companies are interested. San Rafael, CA-based Industrial Light and Magic used similar techniques to create explosions for *Terminator 3*. But making fire animations easy to control and ready for film production will take another year or two, says Fedkiw. Other applications include virtual-reality training for firefighters.

A simulated flame.

COURTESY OF RON FEDKIW (GREAT BALLS OF FIRE); COURTESY OF KEN BIBLE AND WILLIAM KAISER (TREE BOT); COURTESY OF THE COMPUTER VISION AND ROBOTICS RESEARCH LABORATORY, UNIVERSITY OF CALIFORNIA, SAN DIEGO (DRIVERS)

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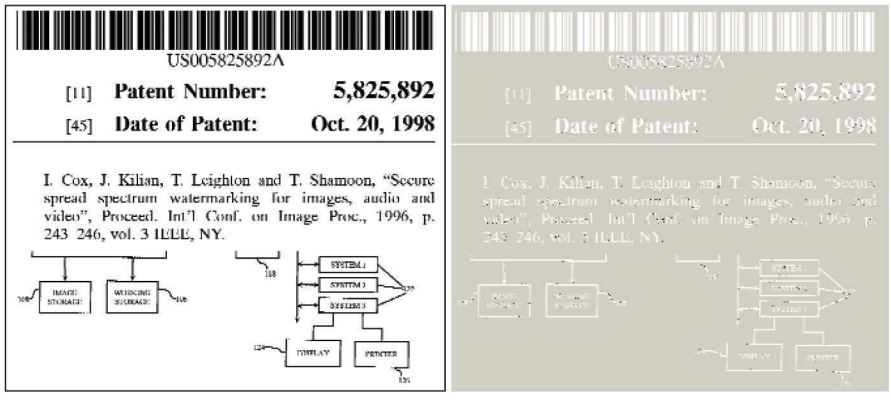
A detector scans a car's trunk for explosives.

BOMB BUSTER

UP TO 40 PERCENT OF CHECKED LUGGAGE FALSELY SETS OFF AIRPORT BOMB DETECtors, wasting time and money, and because the detectors look for suspicious objects rather than explosive chemicals, clever terrorists could still evade them. But HiEnergy Technologies in Irvine, CA, has dusted off a technology abandoned as impractical in the 1980s to create new sensors that can chemically identify explosives, even through steel. HiEnergy's founder and CEO, Bogdan Maglich, says the device sends a harmless amount of neutrons toward an object. It then analyzes radiation induced by the particles to reveal the chemical makeup of the target. HiEnergy's revival of the technology pivoted on its ability to control noise from neutrons hitting objects other than the ones being scanned. The Spanish government has asked the company to develop the technology into a car-bomb detector for use in parking garages; tests of the detector are scheduled for early December, and those of a baggage- and cargo-scanning system could follow in January.

SECURITY IN BLACK AND WHITE

BUSINESSES AND GOVERNMENT AGENCIES NEED A WAY TO AUTHENTICATE THE images they exchange electronically. A classic solution is to hide a "digital watermark" in a color or gray-scale image by making imperceptible changes in the colors or brightnesses of individual pixels. But for black text on a white background, this approach doesn't work so well: flipping even one white pixel to black on a field of white can produce a visible irregularity. Now University of Maryland information scientist Min Wu is perfecting software that adds secret data to such documents by subtly altering pixels in small blocks along the edges of letters, where the changes are virtually unnoticeable. Each block encodes a single binary digit; together, the digits constitute a signature that can be extracted to prove an image hasn't been forged or altered. If it has, the hidden signature doesn't appear, or becomes mush. Wu says officials at Princeton University, where she began work on the software as a PhD student, are talking with potential licensees about putting it to work in commercial document-verification systems.



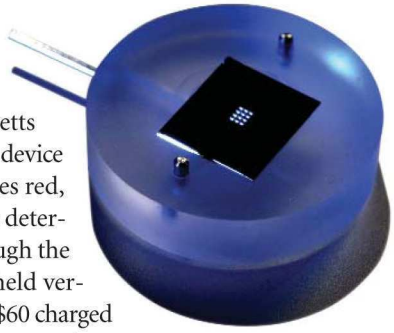
Black dots (right) hide an authentication signature in a document without visibly altering it.

DIGITAL SKETCH PAD

In order to design new devices and programs, engineers must transfer their initial creative sketches from paper to computer-aided-design programs, a painstaking and cumbersome process. MIT computer scientist Randall Davis is on his way to eliminating the paper stage entirely with software that can recognize and interpret shapes sketched right on a tablet computer. When a software designer, say, sketches a rectangle, the program will recognize it as representing a specific programming function. "Once the sketch is understood, you can hand it off to other programs" that transform the sketch into a skeleton code, Davis says. The boon for designers is that they can quickly try out concepts to see how they will work before transferring more elaborate drawings to the computer. While he is still working on prototypes, Davis is already taking the idea one step further, constructing a digital drafting table, whose surface looks like an ordinary desk's but is effectively a large-scale tablet computer screen on which drafters could sketch their designs.

HIV MONITOR

FORTY-TWO MILLION PEOPLE WORLDWIDE ARE INFECTED WITH HIV, AND THE VAST majority of them live in the developing world, with little access to sophisticated labs that can monitor their immune-cell levels—measurements critical to determining their need for and response to drugs. Researchers from the University of Texas at Austin and Boston's Massachusetts General Hospital are developing a portable immune-cell reader to fill this gap. At the heart of the device is a microchip that filters white blood cells out of a few drops of blood and stains the key ones red, green, and yellow. A digital camera then takes a picture of the cells, which software analyzes to determine the counts of each cell type, indicating how well the immune system is holding up. Though the current prototype is the size of a desktop computer, the researchers aim to produce a handheld version within the year. Ultimately, they hope each test will cost less than $3, compared to the $35 to $60 charged by conventional labs. Early trials of the system conducted in Boston and Botswana have been encouraging. The researchers say testers in Botswana liked the prototype so much they didn't want to send it back.



A filtering chip is the heart of a cheap, portable blood test.

COURTESY OF MARSHA MILLER, UNIVERSITY OF TEXAS (HIV MONITOR); COURTESY OF MIN WU (SECURITY); COURTESY OF HIENERGY (BOMB BUSTER)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Medicine Goes to the Dogs

THERE ARE PEOPLE—YOU'VE MET THEM—WHO love their pets far more than many parents love their children. Don't mock them. Don't pity them. Be grateful. Odds are their veterinarians will play a bigger role in saving your life—or the life of your sick child—than your own doctor. ■ Veterinarians for pampered pets will soon be in the vanguard of human health care, and the reason is regulatory. Controversial restrictions on embryonic-stem-cell research and cloning effectively squelch efforts to bring these biotechnologies to bear on human therapies. The moral quandaries and bioethical concerns underlying these restrictions can't be dismissed. But the different standards we apply to animals create provocative loopholes for the innovative and opportunistic biomedical entrepreneur.

Please follow the money. Legally, ethically, morally—and yes, even financially—pet lovers are superbly positioned to fund breakthrough biotechnology treatments and genetic therapies for their loved ones. Americans now spend $19 billion a year on veterinary care, up from $11 billion just seven years ago, according to a recent *New Yorker* article on pet care. That $19 billion figure approximates the research and development budget for the National Institutes of Health, which oversee public medical research funding in the United States. The rate of growth remains robust.

But even more significant than mere money is the rapidly increasing sophistication of veterinary care. Little more than 20 years ago, the *New Yorker* observed, all vets were general practitioners, and neutering and spaying were among the most elaborate procedures they performed. Today you can take your pet to a veterinary cardiologist, oncologist, radiologist, or ophthalmologist—indeed, the American Veterinary Medical Association now includes more than 7,000 such specialists.

There is no way that gene, stem cell, or cloning therapy for cats and dogs will not yield immediate insights for human medical research.

My only objection to the *New Yorker*'s otherwise superb survey is that it didn't go far enough. It ignored the additional benefits that canines and felines alike are likely to reap from the tremendous amounts of biotech-driven research currently under way.

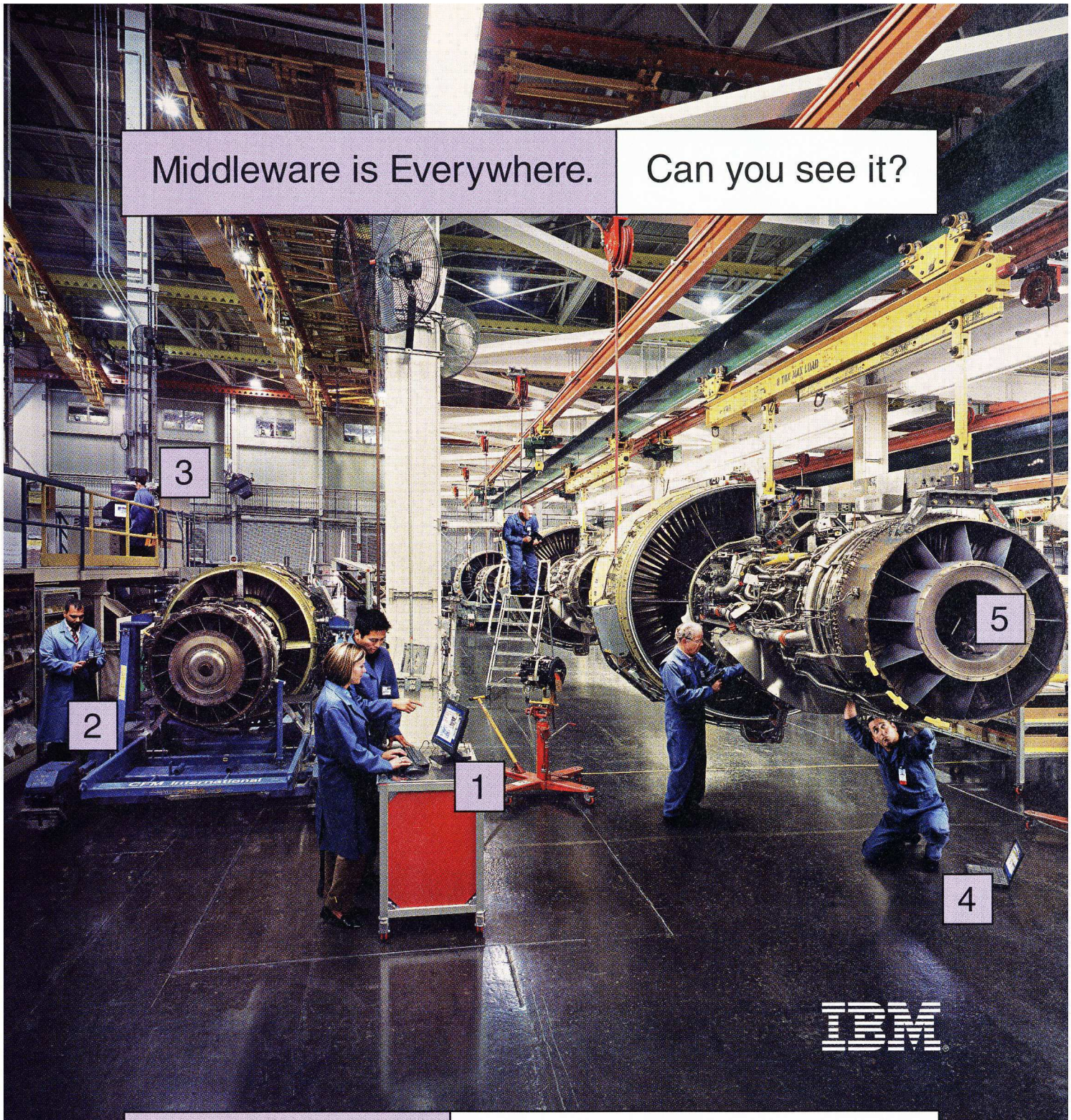
A cat crippled by leukemia or a dog suffering from a degenerative autoimmune disease might indeed be a perfect candidate for embryonic-stem-cell therapy. Cloning tricks and techniques that might be inappropriate for people—Goodbye, Dolly—could well represent appropriately heroic intervention by a pet-driven biotech initiative. Yes, many people understandably blink at the thought of spending $10,000 to save a cherished pet. But market forces reveal that there are tens of thousands of pet lovers who don't. All it would take is one Labrador-loving billionaire to create the veterinary counterpart to the Howard Hughes Medical Institute—an enormously influential philanthropic funder of innovative biotech.

If veterinary biotech comes anywhere close to attaining its promise, patients with names like Rover, Fido, Spot, Buddy, and Cassandra will be the medical marvels that transform the legal, ethical, and regulatory marketplace for biotech innovations for their human masters and guardians. Technically, it is already clear that the human genome and the dog genome, for example, are remarkably similar. (About three-quarters of human genes have direct canine counterparts, according to a recent study funded by genomics pioneer J. Craig Venter's Center for the Advancement of Genomics and the Institute for Genomic Research.) There is no way that gene therapy or stem cell therapy or cloning therapy for cats and dogs will not yield immediate and useful insights for human medical researchers.

The very effectiveness of veterinary biotech would subvert the regulatory and ethical underpinnings of human-research constraints. It's almost impossible to imagine society saying, "It's all right to use embryonic stem cells to save your dying dog, but it's not okay to use them to save your dying child." It's impossible to imagine a president or a senator or the CEO of an HMO asserting that a controversial biotech therapy that puts a cat's leukemia in remission must never be used to treat a sickly adolescent. Ain't gonna happen.

The conclusion? America's love affair with animals will slowly but inevitably undermine the religious, moral, and ethical arguments against genome-based therapies for people. Healthier cats and dogs will generate an irresistible demand for healthier children and adults. Wealthy pet lovers will be the essential instrument of innovation adoption that will drive the next generation of medical treatments. Tomorrow's biotechnical health-care challenge will literally be going to the dogs. I mean that in a good way. So should the medical community.

Michael Schrage is a consultant and researcher who writes widely about innovation.



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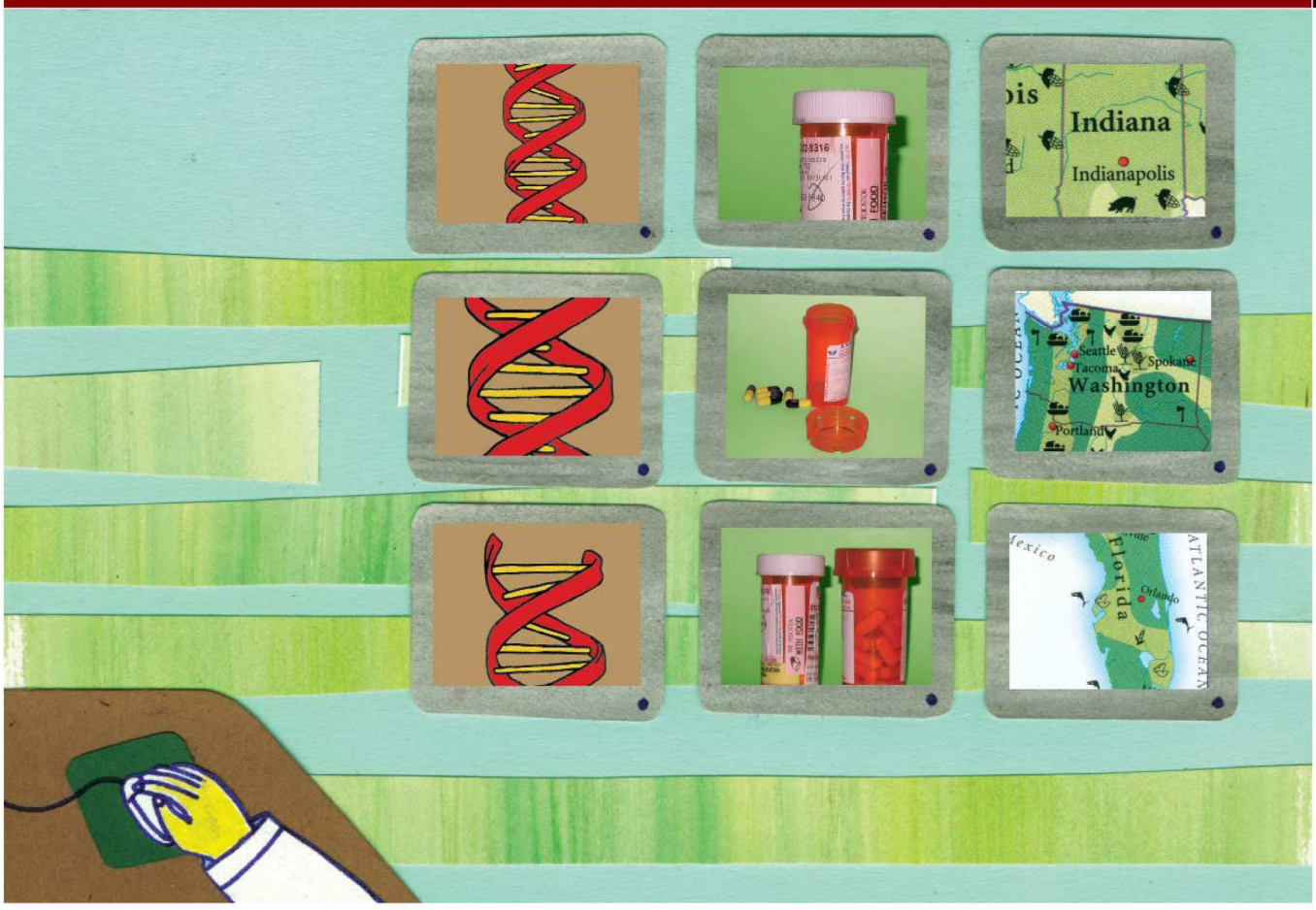


Diagnosing with Data

The Mayo Clinic is transforming medicine with advanced computing. **BY GREGORY T. HUANG**

Even a top-notch specialist like Piet de Groen, a gastroenterologist at the Mayo Clinic in Rochester, MN, can't know everything about every illness his patients may suffer. But on the rare occasions that he encounters an ailment he's never seen before, chances are another physician at the hospital has. So de Groen is developing an electronic "data warehouse" that allows him to type in a patient's symptoms and—within seconds—get a list of all similar Mayo patient records. By 2004, after initial data security and patient confidentiality issues have been resolved, de Groen and his colleagues will be able to use these histories to make more accurate diagnoses. In the long term, they could even access your genetic profile to help choose a course of treatment.

The Mayo system is being built with the collaboration of IBM Life Sciences in Rochester and in Yorktown Heights, NY. Started in the winter of 2002, the project has already produced a large database of medical records and software that can find groups of patients with similar conditions and treatments. While hospitals and HMOs are increasingly using electronic records to track patient histories, the Mayo system goes further. It automatically groups patients according to the factors they have in common, allowing doctors to search quickly for combinations of factors. It will be used first for medical research but ultimately to improve patient care. "The application of information technology and bioinformatics is moving toward medicine and patient care much more rapidly than anyone anticipated," says Carol Kovac, general manager of IBM Life Sciences.

The Mayo's data warehouse contains 4.4 million patient histories recorded over the past five years. Doctors can search these records by symptoms, age, patient's

MARTINA WITTE

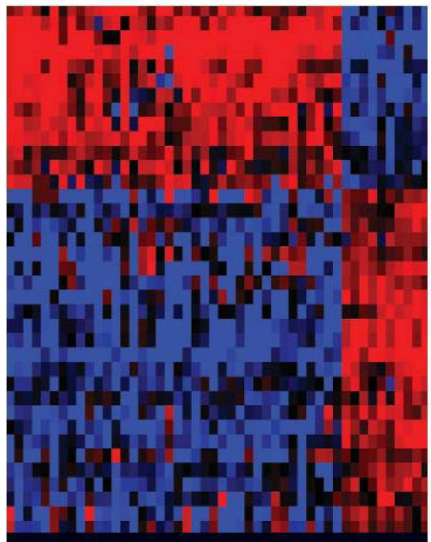
home state, date of diagnosis, and other factors; in 2004, drug information will become available as well. Because the records are already clustered according to common characteristics, searches can zero in on the most likely matches, instead of poring through the entire database patient by patient. When a new patient's information is entered, software automatically compares it with existing patterns and groups it accordingly. The result: the system could eventually operate fast enough to be used during a visit to the doctor's office. So the doctor might, for example, check how older female patients with a specific set of symptoms respond to a particular drug.

But doctors and patients want more. They want to know why drug therapies work for some but not others; which people are more susceptible to cancer; and ultimately, what the best treatment is for each individual. For these kinds of queries, clinicians need access to genetic information, such as that gleaned from microarrays that provide snapshots of the activity levels of thousands of genes. "Using genomics to affect the way medicine is done, and making a secure repository of information that doctors can access—these avenues will converge," says Gustavo Stolovitsky, a computational biologist at IBM.

As a first step, researchers at IBM have developed smarter software to find patterns in large groups of genes that signify whether a group of patients with common symptoms has a certain variation of a disease—which should lead to better diagnoses for individuals. For example, the scientists developed a genetic screen for leukemia using algorithms that can efficiently examine large numbers of gene combinations. They used it to identify a unique signature of about 100 genes in Mayo patients with a common form of leukemia *(see image, this page)*. In a separate test at Columbia University, doctors used the screen to diagnose the disease, with 100 percent accuracy. The hope is that the analysis software can be extended to other cancers and to cardiovascular disease.

Down the road, databases that incorporate such genetic data, combined with pattern recognition algorithms, could allow doctors to detect disease before symptoms emerge and create treatment plans customized to patients. "I am convinced," says de Groen, "that in five years, for some tumors, we'll be able to say, 'We know from your DNA and study of your tumor that this drug will work, and with little toxicity.'" But translating prototypes into practical systems that can handle the extra genomic data and still be searchable—and affordable—will take a while.

Critical to implementation of the systems is overcoming concerns about security and patient privacy. In addition to enforcing "military-level security" on patient data, says de Groen, clinicians "have to make people understand that there are tons of benefits in having their information available." And, he adds, policymakers must ensure that such medical information cannot be hijacked or used to deprive patients of insurance or other services. Currently, use of the Mayo database is restricted to project coordinators. But starting in January 2004, password-protected access will gradually be granted to Mayo doctors who file protocols that demonstrate a need to use the data in their research. Longer-term plans call for the database to be accessible to any doctor with a patient waiting in his or her office.



High levels of activity (red) in certain genes distinguish 38 leukemia patients (vertical columns, left) from 10 healthy subjects (right).

COURTESY OF IBM

Ultimately, after the technical and social issues have been resolved, collaborations between infotech companies and clinicians will mean widespread improvements in patient care. "It might take a decade, but information will transform medicine for the ordinary Joe on the street," says IBM's Kovac. If she's right, a quick database search might become a standard part of any medical checkup. TR

PROJECTS USING ADVANCED DATABASE TOOLS IN MEDICINE

INSTITUTION	APPLICATION/STRATEGY
Duke University School of Medicine (Durham, NC)	Combining genetic markers, medical images, and clinical histories in an electronic health-care database
Hadassah Hospital (Jerusalem, Israel)	Integrating gene expression profiles and medical images into electronic patient records
iCapture Research Centre, University of British Columbia (Vancouver, British Columbia)	Correlating genetic markers and environmental factors with heart and lung diseases, using pattern discovery algorithms
Kobe General Hospital (Kobe, Japan)	Integrating patient records and genetic data for personalized care
Mayo Clinic (Rochester, MN)	Unifying patient records in a single cross-searchable database; later versions will include genomic information
University of California, San Diego, School of Medicine (San Diego, CA)	Testing a secure database that allows doctors and patients to access clinical records over the Internet; developing faster computing tools to analyze gene expression for diagnosis and treatment of cancer

TELECOM

Wireless Goes Farther

Wi-Fi has untethered web surfers from phone and network cables, but users still can't stray more than about a hundred meters from a transmitter before they lose their connections. A wireless technology with better range may soon cut this invisible leash.

The Institute for Electrical and Electronics Engineers is standardizing a technology called 802.16, or WirelessMAN, for Wireless Metropolitan-Area Networking, which should enable computers to communicate wirelessly over kilometers. At least 25 companies, including Intel and Nokia, have joined the WiMAX Forum, an industry group that is forming to promote the new technology. Products compliant with the standard should begin hitting retail stores' shelves by the end of 2004.

This transceiver provides wider coverage.

WirelessMAN proponents believe the new standards will allow broadband wireless to take off at last. "Some people predict that there will be tens of millions of broadband customers worldwide in four or five years," says Mohammad Shakouri, vice president of business development at Alvarion, a Tel Aviv, Israel-based wireless-broadband company. "I think that's an underestimate."

While Wi-Fi—as IEEE's 802.11b standard is popularly known—connects computers to the Internet via a wired modem, WirelessMAN is a completely wireless broadband technology. In its ultimate implementation, base stations mounted on buildings or cell-phone towers will beam radio signals to a wireless modem in every WirelessMAN-enabled device. In addition, higher-power transceivers allow WirelessMAN to provide wireless communication over tens of kilometers, so users can access the Internet virtually anywhere in a city. Differences in the way WirelessMAN coordinates radio communication between base stations and users make the service more reliable and up to six times faster than cable, DSL, or Wi-Fi—at least in theory. Connection speeds will depend on the number and proximity of the base stations.

While the technology is ready, whether it can beat existing broadband Internet access on speed or cost is debatable. "I haven't seen anything that makes me think that it will be viable in places where DSL and cable are well established," says Charles Golvin of Forrester Research in Cambridge, MA. Some analysts estimate the monthly cost for WirelessMAN Internet access could be double that of DSL or cable.

WirelessMAN proponents say the technology will gain a foothold first in areas without high-speed Internet and will eventually compete with DSL, taking advantage of the growing hunger for both high-speed and wireless Internet access. —*Corie Lok*

SECURITY

Vein Check

Fingerprint scanners may seem the ultimate in identification technology, but tricking them is actually not all that hard. Now, scanning the pattern of veins on the back of the hand promises a more reliable system.

Vein recognition is already used in South Korea and Japan to control access to secure rooms in hospitals, factories, and office buildings. System manufacturers say each person has a unique vein pattern, which can be captured by infrared cameras. The technology has been more widely accepted than fingerprinting in Asia mainly for cultural reasons, says Michelle Shen of ePolymath Consulting in Toronto. "In Japan, they are very concerned about hygiene. They're reluctant with fingerprinting because they have to touch the sensor."

With vein recognition, users merely hold their hands up to a scanner.

A second generation of the technology is coming to North America. In 2003, Seoul, South Korea-based Techsphere, one of the first and largest vein recognition companies, signed a deal authorizing Toronto-based Identica to distribute its products in North America. Identica recently sold seven units to the Toronto and Ottawa airports to control ground crew admittance through doors. "Their hands aren't always clean, and that would give false readings all the time with fingerprinting," says Edward Foster, president and chief operating officer of Opus Canada, a flight services provider to the Toronto airport.

Vein recognition is so new to North America that there hasn't yet been much independent testing of the technology, leading to skepticism from some experts. The adequacy of the approach has yet to be established through third-party testing, says Larry Hornak, director of the Center for Identification Technology Research at West Virginia University. But with more testing, perhaps more people will be checking their veins at the door. —*Corie Lok*

A scanning device checks vein patterns.

COURTESY OF IDENTICA (VEIN); COURTESY OF WI-LAN (WIRELESS)

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INTELLECTUAL PROPERTY

Academic Patent Binge

Patent activity at colleges has jumped in both quantity and quality over the last five years. Data provided exclusively to *Technology Review* by CHI Research in Haddon Heights, NJ, which ranks universities by technological strength (a measure combining both the number of patents issued and their relevance) reveal how great the upsurge is. In fact, in 2002, 13 of the top 25 universities saw a 50 percent or greater increase over the number of patents issued in 1997, six of which have seen increases of 100 percent or more *(see table, this page)*.

At some institutions, a mere handful of discoveries helped bump up rankings. John Ritter, director of Princeton University's Office of Technology Licensing and Intellectual Property says its jump from 43rd in 1997 to sixth in 2002 may be due to heavily cited patents, such as one for a three-color organic light-emitting device that could yield more-efficient flat-panel displays.

With the patent boom has come growth in the number of university-related startup companies and in income from patent licensing. The Association of University Technology Managers' annual licensing survey shows total university income from patents increasing from $699 million in 1997 to $1.07 billion in 2001. Patenting by universities has "just come into its own in the last five years," says Patricia Harsche Weeks, president of the Association of University Technology Managers and vice president of the Philadelphia-based Fox Chase Cancer Center.

That trend also reflects the entrepreneurism that has taken root on campuses. More and more, researchers are taking time away from the lab to write patents, consulting on technology licensed from their labs, and even taking leaves of absence to found companies and commercialize technologies. "No longer are faculty satisfied with publishing," says Mark Coburn, associate provost and director of the Office of Technology Transfer at the University of Rochester. "They have the sparkle in their eye to start their own business."

Coburn believes that their passion isn't merely a matter of financial incentive. "Entrepreneurship in a university is a good thing," he says. "It's not just for starting a business. [It] can lead to innovative educational initiatives, research breakthroughs, and a greater recognition of the university's role in the community." With consequences like those, university patenting will benefit more than just a school's bottom line. —*Tracy Staedter*

	TECHNOLOGICAL-STRENGTH RANKING		NUMBER-OF-PATENTS RANKING		TECHNOLOGICAL-STRENGTH SCORE		NUMBER OF PATENTS			CURRENT-IMPACT INDEX	
INSTITUTION	1997	2002	1997	2002	1997	2002	1997	2002	% CHANGE	1997	2002
University of California	1	1	1	1	310.8	496.7	305	466	53	1.02	1.07
MIT	2	2	2	2	154.9	265.6	107	152	42	1.45	1.75
Stanford University	6	3	4	4	75.3	165.9	67	110	64	1.12	1.51
Caltech	7	4	10	3	73.5	165.6	50	117	134	1.47	1.42
University of Texas	3	5	3	5	130.1	98.8	92	106	15	1.41	0.93
Princeton University	43	6	18	17	23.4	75.9	17	38	124	1.38	2.00
University of Wisconsin	8	7	5	7	71.6	74.6	63	82	30	1.14	0.91
Johns Hopkins University	10	8	6	6	62.1	74.1	61	95	56	1.02	0.78
University of Washington	5	9	12	13	88.3	70.7	45	44	-2	1.96	1.61
University of Michigan	4	10	8	8	90.3	63.2	58	57	-2	1.56	1.11
University of Chicago	17	11	10	9	39.9	56.0	50	55	10	0.80	1.02
North Carolina State University	22	12	14	16	30.3	54.4	27	39	44	1.12	1.40
University of Southern California	33	13	16	18	25.2	51.6	21	36	71	1.20	1.43
Pennsylvania State University	31	14	17	9	25.5	51.5	20	55	175	1.27	0.94
Georgia Institute of Technology	72	15	18	18	12.9	45.6	17	36	111	0.76	1.27
Columbia University	15	16	13	12	47.8	45.4	38	47	24	1.26	0.97
Cornell University	12	17	9	15	56.7	45.4	53	40	-25	1.07	1.14
University of Pennsylvania	9	18	7	11	70.6	45.0	59	49	-17	1.20	0.92
Rutgers University	25	19	15	14	27.8	43.7	23	43	87	1.21	1.02
Carnegie Mellon University	67	20	20	21	13.9	42.8	9	19	111	1.55	2.25
Duke University	24	21	14	14	27.8	41.4	27	43	60	1.03	0.96
Harvard University	19	22	13	10	35.9	39.2	38	52	37	0.95	0.75
Emory University	27	23	19	19	26.5	38.1	14	30	114	1.89	1.27
University of Rochester	81	24	21	20	11.2	37.4	8	20	150	1.40	1.87
State University of New York	13	25	11	10	48.7	36.7	48	52	8	1.01	0.70

Technological strength: The number of patents multiplied by the current-impact index *(see below)*.
Number of patents: The total number of U.S. patents awarded, excluding design and other special-case inventions.
Current-impact index: A measure of how frequently an institution's patents from the previous five years are cited in the current year, relative to all patents in the U.S. system. A value of 1.0 indicates average citation frequency.

SOURCE: CHI RESEARCH

INTERNET

Networking's Next Level

If you want to win friends and influence people, social-networking Web sites such as Friendster, Ryze, and LinkedIn can help you do it at Internet speed. These sites typically allow users to create online profiles, then build "personal networks" by linking to the profiles of friends or associates. *Their* friends and their friends' friends then become potential collaborators, employers, or dates. It's one of the hottest crazes on the Web, supplementing e-mail, blogs, and personal ads as a way to make connections.

Limiting the utility of online social networks, however, is the fact that one site's members can't connect with another's, so people who want to use more than one site must build separate networks. "Being able to connect the various presences you have in cyberspace is key," says Marc Canter, CEO of San Francisco-based Broadband Mechanics. He's talking with Tribe.net (also of San Francisco) and other companies about building a giant network of social-networking sites that would allow users to cross site boundaries.

Essential to the project are new Web technologies such as Friend-of-a-Friend, a data-formatting scheme designed by a loose coalition of programmers and based on a language created by the Cambridge, MA-based World Wide Web Consortium. The scheme provides a standard set of labels for items of personal information such as name, title, e-mail address, place of employment, or hometown. These labels also allow users to create lists of acquaintances that can be understood and exploited by specialized search engines. Is someone you know friendly with the boss at the company where you covet a job? If your favorite networking site provides the technology, a search engine could unweave a lacework of interconnected Friend-of-a-Friend files to find the answer and get you an introduction. —*Wade Roush*

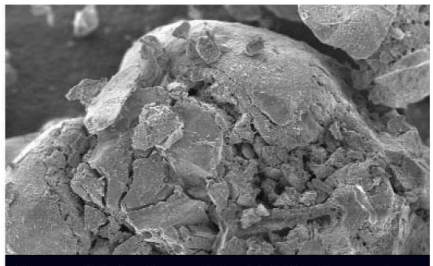
COURTESY OF THE UNIVERSITY OF WISCONSIN-MADISON

MATERIALS

Making Cheaper Hydrogen

HYDROGEN-POWERED FUEL CELLS COULD PROVIDE EFFICIENT, RELIABLE power for everything from buildings to autos and wireless devices. But there's a big problem: how do you get the hydrogen in the first place?

The most common methods of producing hydrogen—separating it from steam, extracting it from methanol or biomass such as corn, or simply splitting water into oxygen and hydrogen—are expensive and make the so-called hydrogen economy seem decades away. Scientists are making progress, though, by improving the catalysts employed in many of these hydrogen-producing reactions. Common catalysts have included precious metals like gold and platinum. But researchers at the University of Wisconsin-Madison have constructed a catalyst from nickel, aluminum, and tin that could be hundreds of times less expensive and still accelerate reactions involving either methanol or biomass. "Using a nickel-based catalyst can greatly reduce costs, especially for a larger reaction," says Randy Cortright, a member of the Wisconsin team who founded Virent Energy of Madison, WI, to commercialize the method.



A new nickel-alloy catalyst (100-micrometer portion shown) helps make cheap hydrogen.

Cheaper materials are just part of this cost equation. James Dumesic, head of the Wisconsin team, says finding "catalysts that are either more active or will work at lower temperatures" is another crucial step. Most commercial hydrogen today is produced in natural-gas power plants by reacting steam and methane over a catalyst at high temperatures. But cooler reactions requiring less energy could make smaller-scale hydrogen production affordable. Researchers at the Georgia Institute of Technology have developed a new process, which involves adding iron to the catalysts, that can lower the temperature of hydrogen-producing reactions—conceivably making hydrogen energy, in the long run, cheap enough that commercial buildings or homes could have their own power supplies.

To spur further innovation, in January the U.S. Department of Energy will announce as much as $80 million in grants for hydrogen production research. And scientists think continued tinkering with new catalysts can bring hydrogen power into the mainstream. "This materials breakthrough is going to happen," says John Turner, a principal scientist at the National Renewable Energy Laboratory in Golden, CO. "We just don't know when." —*Peter Dizikes*

CATALYST CATALOGUE

GROUP	TYPE OF REACTION	FUEL SOURCE	CATALYST MATERIALS
University of Wisconsin-Madison, Virent Energy (Madison, WI)	Liquid reforming of hydrogen from sugars	Biomass feedstocks such as glucose	Nickel, tin, aluminum
Georgia Institute of Technology (Atlanta, GA)	Steam reforming	Natural gas	Iron added to cerium oxide, praseodymium oxide terbium
Tufts University (Medford, MA)	Water and carbon monoxide make hydrogen and carbon dioxide	Natural gas or other fossil fuels	Cerium oxide with one-tenth the gold previously used
National Renewable Energy Laboratory (Golden, CO), **University of Hawaii** (Honolulu, HI), **University of California, Santa Barbara**	Splitting water into oxygen and hydrogen	Sunlight and water	Silicon and metal oxide compounds integrated into solar cells

Lunch Is on Me

AS A REASONABLY SUCCESSFUL ENTREPRENEUR, I frequently get lunch invitations from extraordinarily bright and energetic startup founders who seek my advice (for whatever that's worth) and, inevitably, my money as a private individual or "angel" investor. I rarely say no to lunch (even though I'm buying), rarely say yes to investing, but I always find the stories fascinating. ■ I'm fairly certain that a would-be angel investor has better odds of making a killing by taking his or her $50,000 to a Vegas roulette table and smacking it all down on 22. Yet over countless lunches between friends, family, coworkers, roommates, and friends and family of all the above, tens of millions in angel money are invested each year, providing vital cash to embryonic startup companies around the globe.

The scudding economy has made the angel's role even more critical. With few exceptions, conventional venture capital firms are still reeling from the high-tech/dot-com implosion. Venture capital funds continue to plough money into life support for their existing portfolios of bad investments in the hopes (most likely vain) that the economy will rapidly recover and their companies can claw their way toward profitability. The venture capitalists that still have money to spend on new investments have gotten gun shy and are staying well clear of seed-stage startups in favor of more mature, revenue-producing operations.

Jon Flint, a managing general partner of Waltham, MA-based Polaris Ventures, which is one of the more successful East Coast venture capital firms, once opined to me that "like great artistic talent, the number of excellent, investable startups that emerge each year is a constant." By that principle, the current drought in seed-stage investing is just as irrational as the venture-financing exuberance of the late 1990s. Almost by definition, the next eBay or Microsoft must be out there, overlooked or ignored by the venture capitalists.

Why bet in a casino that makes you wait outside while the game is played? Because passion, not reason, drives angel investments.

Unfortunately, just picking a winner is only the first trial in a gauntlet of trouble that waits for angels. As further investments come in, the angel's share in the company (and thus of future rewards) can be diluted right out of the water by more aggressive and savvy professional investors. An angel whose initial ownership is 10 percent of a company might wind up, three years down the road, owning less than 1 percent—without oversight of or influence on the management decisions in between. And while the goodwill and financial incentives of a company's founders are critical to its success, later funders care little about what happens to the angel's stake.

So why do it at all? Why bet in a casino that takes your money but makes you wait outside while the game is played? I think the answer is that angel investments are decisions of the heart, driven by passion rather than clinical assessments of risk and return. An entrepreneur tells a story about what just might be and kindles the investor's sympathy for a group of people, their ideas, and their vision of changing the world. And if in the process, as occasionally happens, an angel can turn the price of a golf cart into the price of a Gulfstream, what could be better?

In each of my columns, I will be featuring a different startup that is looking for private investment, considering the company not just from the gee-whiz technology angle, but also from the perspective of a would-be angel. For obvious ethical reasons, I have no financial interests in any of the firms I'll be writing about, and I am not endorsing them as investments in any way. Rather, I'll be selecting the stories of people who have unique and fascinating pictures in their minds of how the future might be different, if only their companies can succeed.

OVATION PRODUCTS

How would you feel about drinking a glass of water distilled from your own raw sewage? You've no doubt just experienced what Bill Zebuhr, founder and CEO of Nashua, NH's Ovation Products, calls the "yuck factor"—which may present a major hurdle to market acceptance of his household water distiller. Then again, it may not. If, for example, you live in a part of the world where your drinking water is already directly contaminated by sewage (yours and your neighbors'), the distilled option is clearly more palatable, and one that might save your life. Or perhaps, if you can't quite bring yourself to take a sip, you might not balk at watering your lawn or washing your car with the output of Ovation's machine. Especially when you consider that distilled water is as pure as water gets.

Zebuhr claims that his distiller can take water contaminated with virtually anything, from pathogens to toxic chemicals, and produce 45 liters of pure distilled water each hour for the astonishing price of more than five liters per penny. The device looks a bit like R2-D2 with extra tubes hanging out, and while I'm certainly no expert, it appears to be a tour de force of thermodynamic engineering, an area in which Zebuhr special-

izes and holds more than two dozen U.S. patents. Contaminated water, at room temperature, is boiled into steam, and the steam is compressed and condensed into pure distilled water. Through a series of innovative heat exchangers, the pure water also leaves the system at approximately room temperature, largely conserving energy within the system. (Its droidlike appearance comes from encasing the entire mechanism in a stainless-steel dewar, which acts like a giant thermos.)

Zebuhr's vision is that someday every house, apartment building, and Third World village will have an Ovation distiller humming away, recycling wastewater into drinking water and eliminating the need for central water and sewage treatment plants, as well as endless kilometers of connecting pipes. While the market opportunity for cheap drinking water is mind-bogglingly vast, Ovation is attacking some richer niches first.

Zebuhr explains that more than 150,000 household septic-system leach fields (the areas where wastewater is purified by percolation through the soil) fail each year, requiring some form of expensive remediation. He holds a patent on a process for distilling septic-tank waste to separate out pure water for reuse (though not necessarily drinking), effectively eliminating the need for the leach field in the first place. Zebuhr's back-of-the-envelope calculation holds that while leach field remediation usually costs between $10,000 and $40,000, Ovation can build distillers in quantity for around $1,000 each. He places the total septic-tank remediation market at more than $1 billion annually, yielding considerable revenue opportunities if he can successfully attack the market.

Zebuhr and his team are also making a foray into cleaning industrial-waste runoff, where they believe they can cheaply remove clean water from toxic chemical solutions—enabling factories to drastically reduce the cost of pollutant disposal. The Ovation team notes that in certain situations, such as the washing of machine parts, distillation is the only viable process for separating toxins from the water in which they are dissolved.

Ovation was founded in 1996, and after seven years of development, it appears to be on the verge of bringing in its first sales from the industrial-cleanup market. Those sales, however, are contingent on successful production of a beta version of the distiller. Every startup runs a race between generating sufficient revenue and running out of money (an event affectionately known as the "splatter date"), but in Ovation's case, the contest has hit a particularly dramatic stage. The alpha distiller apparently works, but not well or reliably enough for commercial production and sales. The beta model is well under way, but Ovation's splatter date is rapidly approaching.

Ovation has spent about $6 million to get this far, mostly invested by angels and an anonymous strategic partner, and Zebuhr believes he has around $700,000 in new investment committed, buying six months of extra runway. He hopes to find a few more angels to provide some room for error, despite his firm belief that he'll have his beta in production and into the hands of paying customers in early 2004. But Ovation is a bit long in the tooth to still be out looking for angel money.

SCORECARD

ELEVATOR PITCH	Universal appliance for producing clean water
FUTURE VISION	Household distillers will be as common as refrigerators, allowing people to produce their own pure and safe drinking water
CEO'S INSOMNIA	How to get the product out of the prototype stage and into mass production before the money runs out
LEAD INVESTORS	Polaris Venture Partners, Cardinal Partners
LEG UP	Patent protection, engineering know-how, first mover

Conventional wisdom in technology startups is that the "mad scientist" founder can never make a good long-term CEO, and Zebuhr takes pains to emphasize that he is open to a replacement should the need arise. But I got the distinct impression that this veteran of several startups is in fact rather attached to captaining his own ship, having had some difficult experiences in the past. It seems to me that managers accumulate business experiences like bad girlfriends or boyfriends: once they're burned in some particular way, they go through the rest of their lives ultrawary of being burned the same way again. Nonetheless, Zebuhr has what I see as a critical attribute for an entrepreneur: he knows his own mind and sticks to his guns. Often in a startup it's better to be decisive than to be entirely right.

For now, Zebuhr is sticking to his belief that there are endless applications for a low-cost water distiller, from the industrialized West, where a household device can pay for itself in water- and sewage-bill savings, to the Third World, where the widespread lack of safe drinking water is perhaps the biggest threat to human health. Ovation also sees a tremendous opportunity in homeland security, where the poisoning of central water supplies has been identified as a major terrorist threat against which there are currently no practical protective measures.

But like all startups, especially those that seek private investment, Ovation has some formidable obstacles to clear, most notably finally getting the product to beta and then on to production. And then there's the yuck factor, which may stand in the way of the full realization of Zebuhr's water-recycling vision. Would you take that sip? TR

Joe Chung cofounded Cambridge, MA-based Art Technology Group, which went public in 1999 and made millionaires of many of its angel investors. Neither *Technology Review* nor Joe Chung holds any financial interest in the companies profiled nor endorses them as investments.

PHOTOGRAPH BY HOLLY LINDEM

THE WEB'S NEW

CURRENCY

MICROPAYMENT TECHNOLOGY IS REVIVING WEB BUSINESSES BY LETTING THEIR CUSTOMERS BUY ENTERTAINMENT AND SERVICES WITH DIGITAL POCKET CHANGE. BUT WILL STARTUPS LIKE PEPPERCOIN SUCCEED WHERE OTHER E-PAYMENT COMPANIES HAVE FAILED?

BY GREGORY T. HUANG

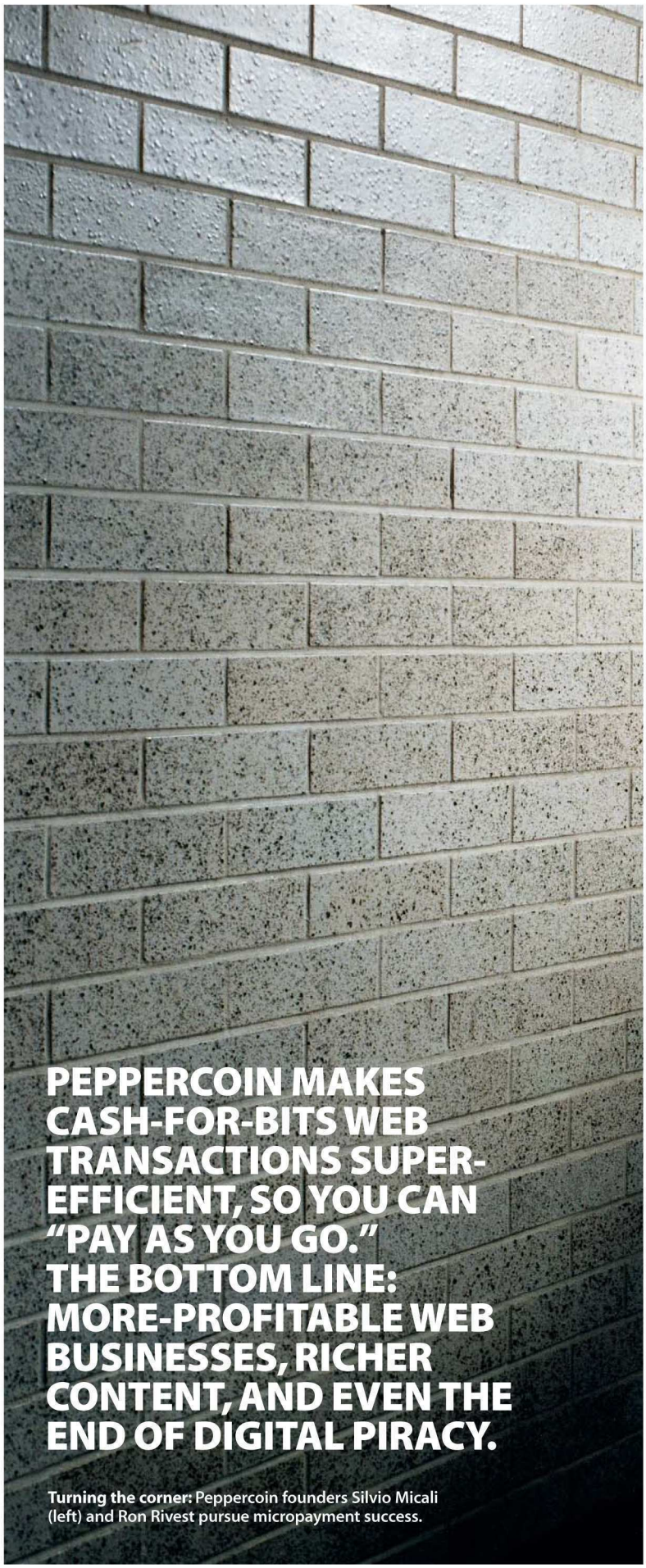
ASK RON RIVEST if he's ever been whisked away by the CIA in the middle of the night, and he laughs—but he doesn't say no. At Peppercoin, a two-year-old MIT spinoff in Waltham, MA, the renowned cryptographer oversees an operation far less secretive than an intelligence agency but almost as intense: a clearinghouse for electronic "micropayments," pocket-change transactions that may finally allow magazines, musicians, and a multitude of others to profit from selling their wares online. It's September, and with only weeks to go until commercial launch, Peppercoin's software engineers troubleshoot at all hours. Marketing executives shout across the room and over the phone, making deals.

But in the eye of the storm, Rivest is calm and collected. Eyes sparkling, real change jingling in his pocket, he even wears sandals with authority. What Peppercoin is trying to do, he says, is make it easy to "pay as you go" for inexpensive Web content—so you won't need to pay subscription fees, limit yourself to free content, or share files illegally. With a click of the mouse—and Peppercoin's software churning away behind the scenes—you can now download a single MP3 from an independent-music site, watch a news video clip, or buy the latest installment of a Web comic from your favorite artist. All for just pennies.

It sounds simple, but it wasn't possible a few months ago. Most Web merchants still can't support micropayments—transactions of about a dollar or less—because the processing fees from banks and credit card companies erase any profit. But Peppercoin, the brainchild of Rivest and fellow MIT computer scientist Silvio Micali, is in the vanguard of a new crop of companies—including BitPass of Palo Alto, CA, and Paystone Technologies of Vancouver, British Columbia—that make cash-for-bits transactions superefficient. These companies' founders are well aware of the string of defunct e-payment companies whose virtual currencies have gone the way of the Confederate dollar. But they've got something new up their sleeves: easier-to-use technology that allows Web sites to accept tiny payments by effectively processing them in batches, thereby cutting down on bank fees.

So throw out your current conceptions of Web surfing. Rather than sifting through pop-up ads and subscription offers, imagine dropping a quarter on an independent film, video game, specialized database, or more powerful search engine. If programmers and Web artists could profitably charge a few cents at a time, their businesses could flourish. And with an easy way for users to buy a richer variety of content, experts say, the current deadlock over digital piracy could effectively dissolve, giving way to a multibillion-dollar business stream that rejuvenates the wider entertainment industry the same way video rentals did Hollywood in the 1980s. Down the road, cell phones, personal digital assistants, and smart cards equipped with micropayment technology could even supplement cash in the real world.

"The key is timing and technology," says Rivest, who thinks Peppercoin has both right. The company's technical credibility, at least, is not an issue. Rivest coinvented the RSA public-key encryption system, used by Web browsers to make credit card purchases secure. Micali holds more than 20 patents on data security technologies and won the 1993 Gödel Prize, the highest award



PEPPERCOIN MAKES CASH-FOR-BITS WEB TRANSACTIONS SUPER-EFFICIENT, SO YOU CAN "PAY AS YOU GO." THE BOTTOM LINE: MORE-PROFITABLE WEB BUSINESSES, RICHER CONTENT, AND EVEN THE END OF DIGITAL PIRACY.

Turning the corner: Peppercoin founders Silvio Micali (left) and Ron Rivest pursue micropayment success.

in theoretical computer science. Their system uses statistics and encryption to overcome profit-erasing transaction fees; the approach is unique and more efficient than its predecessors.

The timing looks good, too—not just for Peppercoin, but for other micropayment companies as well. "One year ago, it was, 'Will people pay?' Now it's, 'How will they pay?'" says Ian Price, CEO of British Telecommunications' Click and Buy division, which uses micropayments to sell articles, games, and other Web content to customers in more than 100 countries. And in September, Apple Computer announced that its online music store sold more than 10 million 99-cent songs in its first four months. Apple's success was the "starting gun for a track meet of companies" planning to roll out pay-per-download services by 2004, says Rob Carney, Peppercoin's founding vice president of sales and marketing.

Indeed, 40 percent of today's online companies would sell content they're currently giving away if they had a viable micropayment system, says Avivah Litan, an analyst at Gartner Research who specializes in Internet commerce. According to Forrester Research, the market for music downloads is expected to grow from $16 million in 2003 to $3 billion in 2008. And a Strategy Analytics report states that mobile-gaming revenues could top $7 billion by 2008. "The market is ready" for micropayments, says Rivest.

Even so, getting the technology to take off won't be easy. Micropayment companies need to make their systems fully reliable, secure, and easy to use. Just as important, they need to increase demand by working with Web businesses to deliver a broader range of digital products. So on the eve of Peppercoin's commercial launch, the question is not whether the timing and technology are good. It's whether they're good enough.

IN STATISTICS WE TRUST

Understanding Peppercoin requires a little history. According to old English common law, the smallest unit of payment that could appear in a contract was a peppercorn. Silvio Micali's wife, a professor of law, suggested that as the name for his startup back in 2001, and it stuck (becoming "Peppercoin" for the sake of clarity). Now, in his office at MIT's Computer Science and Artificial Intelligence Laboratory, Micali is explaining what makes Peppercoin tick. On hand are technical books and papers in neat piles, should we need them. It's simple mathematics, says Micali—but don't believe him.

Micali knows two things: cryptography and coffee. His micropayment analogies involve cappuccinos. There are two standard ways of buying digital content, he says. One is like prepaying for a certain number of cappuccinos, the other like getting a bill at the end of the month for all the cappuccinos you've had. That is, the customer either pays up front for a bundle of content—say, 10 archived *New York Times* articles—or runs a tab that's settled every so often. The problem with both models is that the seller has to keep track of each customer's tab, and the buyer is locked into a particular store or site. But in the spring of 2001 came a "very lucky coffee break" when Micali and Rivest, whose office is just down the hall, put their heads together. "We started discussing this problem, and within minutes we had the basic solution," says Micali. "And we got very excited! First, from the discovery. Second, from the coffee."

What they discovered was a way to cut the overhead cost of electronic payments by processing only a statistical sample of transactions, like taking a poll. On average, Peppercoin might

A PENNY FOR YOUR BITS: HOW PEPPERCOIN WORKS

Peppercoin's software makes micropayments efficient and profitable by processing only a statistical sample of all transactions.

❶ A customer selects an item and sends digital payment (a Peppercoin "token" worth, say, 10 cents) to a merchant's Web site.

❷ The merchant's computer verifies the token and delivers digital goods, such as MP3 files, to the customer's computer.

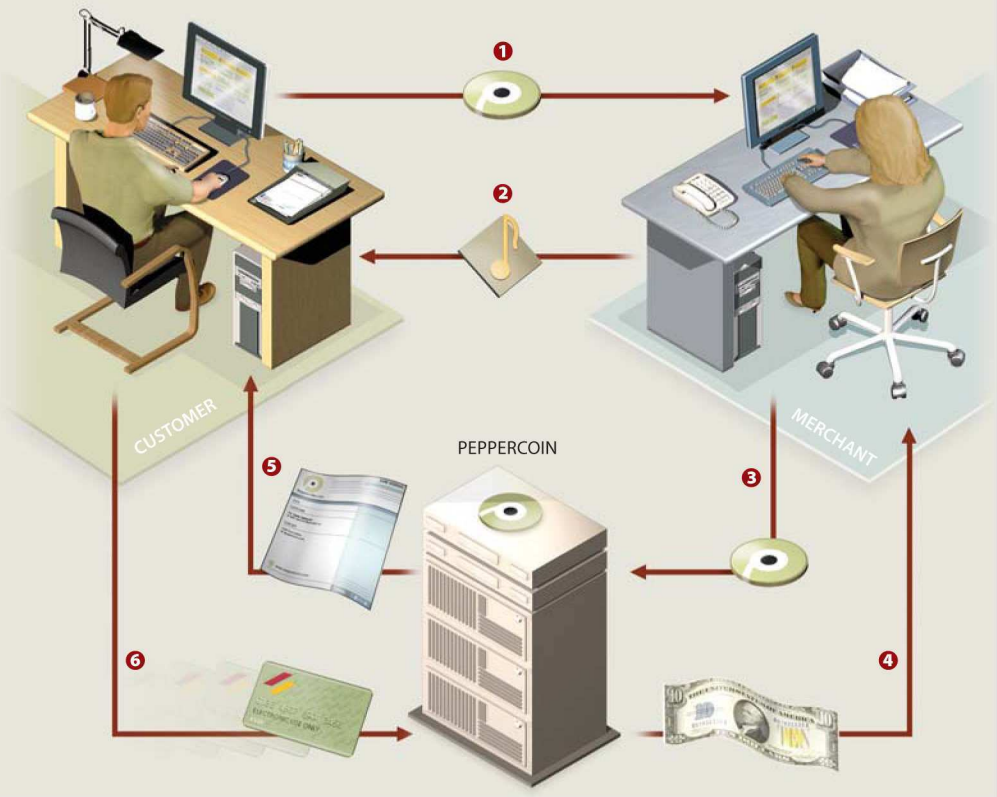
Peppercoin's software randomly selects one token out of every 100 or so for processing. In that case,

❸ The merchant sends the token to Peppercoin. Each token stores a running total of the customer's spending at *all* sites.

❹ Peppercoin pays the merchant 100 times the face value of the token, e.g., 100 x 10¢ = $10.

❺ Peppercoin bills the customer for the exact amount of his outstanding purchases from *all* online merchants.

❻ The customer pays his Peppercoin bill using a credit card.



SW INFOGRAPHIC

settle, say, one out of every 100 transactions—but it pays the seller 100 times the amount of that transaction. Given enough transactions, it all evens out, says Micali.

It looks simple to the buyer, who only has to click on an icon to charge an item to her Peppercoin account, but the action behind the scenes is pretty complicated. In beta tests, special encryption software runs on both the buyer's and seller's computers, protecting their interactions from hackers and eavesdroppers. And encrypted in each transaction is a serial number that says how many purchases the customer has made over time, for how much, and from whom.

Ninety-nine transactions out of a hundred are not fully processed—but they're still logged by the seller's computer. One transaction out of a hundred, selected at random, is sent to Peppercoin. After Peppercoin pays the seller 100 times the value of that transaction, it bills the customer for all of her outstanding purchases from all sites that use Peppercoin. Since about one out of a hundred purchases is processed, her last bill will have come, on average, a hundred purchases ago. That's the trick: by paying the seller and charging the customer in lump sums every 100 purchases or so, Peppercoin avoids paying the fees charged by credit cards—roughly 25 cents per transaction—on the other 99 purchases. "This is fantastic," says Greg Papadopoulos, chief technology officer at Sun Microsystems and a member of Peppercoin's technical advisory board. "Ron and Silvio have done what needed to be done—get the cost of transactions down without ripping up the existing infrastructure of credit cards and banks."

But what's to keep all this fancy statistical footwork from cheating sellers out of their due? And what's to keep buyers and sellers both from cheating the system? "That's the secret sauce," says Micali.

He's talking about cryptography, the sweet science of codes and ciphers. Its inner workings are, well, cryptic—paper titles at conferences include things like unimodular matrix groups and polynomial-time algorithms—but it's used every day to keep communications, documents, and payments secure. Roughly speaking, says Rivest, statistical sampling of transactions makes the system efficient, while cryptography keeps the random selection process fair and secure. So Peppercoin charges users exactly what they owe, and if Peppercoin's payment to the seller happens to be more or less than the value of the purchases customers actually made, the discrepancy is absorbed by the seller. Over time, this jiggle will become negligible, especially compared to the amount of money Web sites will make that they couldn't make before.

Think about it for too long, and most people get a headache. But Micali and Rivest have been thinking about this sort of thing for 20 years, so they make a formidable and complementary team: Micali is as animated as Rivest is understated, like fire and ice. "They've done brilliant work over the years," says Martin Hellman, a professor emeritus of electrical engineering at Stanford University and a pioneer in cryptography going back to the 1970s. "Peppercoin has a clever approach."

But clever mathematics aside, the proof is in the pudding. In the end, Peppercoin's executives say, their system must be as easy to use as cash. Perry Solomon, Peppercoin's founding CEO, explains it this way, pulling some change out of his pocket. "I can give you this quarter, and you can look at it quickly

MISHA GRAVENOR (LEVCHIN); ALLAN PENN (MICALI AND RIVEST, PREVIOUS SPREAD)


Max Levchin

THE PAYPAL PRECEDENT

MAX LEVCHIN believes that micropayment companies' two keys to success are a simple user interface and an aggressive distribution strategy. *TR*'s 2002 Innovator of the Year, Levchin is the cofounder and former chief technology officer of PayPal, the online-payments pioneer that was sold to eBay for $1.5 billion in October 2002.

Technology Review: Are micropayments ready to take off?
Max Levchin: The Apple music store is a good example that 99-cent payments are a reality. What is uniquely different about the market now is that personal publishing has become a lot more pervasive than it was three to five years ago. There are literally thousands of Web sites that specialize in comics, music, and art that's only available on the Internet. [Artists] look to the Internet to actually make money. So demand is definitely increasing. The question is, are these solutions actually what the market needs?

TR: What do Peppercoin and other micropayment startups need to do to become successful?
Levchin: Most of the technical challenge is about the user interface, not the billing process. Overall, Peppercoin's [beta version] user interface is very raw. I have to download software. I have to wait for a confirmation e-mail. What if my computer crashes? You should never force people to download software. The security is a good thing, but it adds complexity.

TR: What's the greatest challenge, going forward?
Levchin: The biggest difficulty, by far, is distribution. How do you get all these people to start using the system? At PayPal, as soon as we "infected" a couple popular eBay merchants, very quickly we saw this massive growth, where buyers started pushing other merchants to sign up. But there isn't a giant market online right now where you can go to look at all digital content available. Digital merchants are very disparate. And consumers aren't going to sign up, download software, or prepay for a card, because there are not that many places to spend it yet. So marketing to digital merchants directly is one way to go. But it will take an incredible amount of human effort to get enough people to sign up.

and say, 'Okay, that's a quarter.' You don't need to call the bank to verify it." Online merchants, however, must check a credit card holder's identity and available credit before approving a purchase. Going to that trouble makes sense for a $50 sweater or a $4,495 Segway transporter, but not for a 50-cent song. So Peppercoin's software stamps each transaction with the digital equivalent of *e pluribus unum*—a guarantee to the seller that it's Peppercoin handling the transaction, and that payment is forthcoming. The seller can quickly verify this stamp and deliver the goods.

BOOTSTRAPPING WITH BITS

The theory may be impeccable, and the founders' credentials outstanding, but how does a startup transform a micropayment system into a practical, sellable product? That's the stuff of late-night whiteboard discussions enhanced by takeout Chinese food and bad TV movies, says Joe Bergeron, Peppercoin's vice president of technology. Bergeron, a baby-faced programming whiz, has the task of translating Rivest and Micali's algorithms into software. Like any good engineer at a startup, he has spent many a night under his desk trying to squeeze in a few hours of sleep. "I'm dreaming in Peppercoins now," he says.

Minting micropayments starts with hardware. A secure data center a few kilometers from company headquarters houses hundreds of thousands of dollars' worth of computing horsepower and memory. All of Peppercoin's money transfers flow electronically through these machines. A rack of 20 processors and backups and four levels of hardware security are set up in a special cage walled off by Plexiglas guaranteed to withstand a 90-minute riot; the rental contract even specifies that the cage will repel "small-arms fire and manual tools."

But Peppercoin's system must also be bulletproof to electronic problems. Take transaction speed, for instance. Peppercoin is working with one Web site that delivers 1,000 digital maps per second. For Peppercoin to handle that many purchases, and for buyers to get their content without waiting, the behind-the-scenes computations must happen in milliseconds. As Bergeron explains, sketching a flow chart on a whiteboard, the software module that identifies what the buyer is paying for, verifies that the payment is good, and sends the digital content to the buyer has been taking a few milliseconds too long in beta tests. The solution: do these steps in parallel, and manage customer queries in a flexible way by devoting more computing resources to the steps that take longer. Trimming bits of fat like this saves precious processing time per click—and ultimately keeps the system running efficiently.

Perhaps even more crucial to Peppercoin's success, though, is its sales strategy. "The challenge isn't getting people to buy the math. It's enabling a new business model for the Web," says Rob Carney. In two respects, micropayment startups are fundamentally different from online person-to-person payment companies like Mountain View, CA-based PayPal, one of the most successful of e-payment companies. First, they are enabling Web merchants to sell low-priced digital content, not physical items. Second, they don't have anything approaching the captive market that PayPal has in the customers who use eBay, the San Jose, CA, online auction house that purchased PayPal in 2002.

So Peppercoin's plan—similar to those of other micropayment startups *(see "The Micropayment Movement," this page)*—is to go after Web merchants, work with them to decide what kinds of content to sell, and build up a brand name with which to approach larger distributors. It's a painstaking process; Solomon and Carney have attended more than 400 sales meetings in two years, trying to persuade merchants that Peppercoin's own fees—which work out to be much lower than the flat transaction fees charged by credit cards—are a small price to pay for the extra business micropayments will generate.

But all this work is starting to pay off. "Peppercoin has been a huge benefit for us," says Rex Fisher, chief operations officer at Music Rebellion, a Terre Haute, IN, company that last June started selling 99-cent MP3s by the download, using a beta version of Peppercoin's system. The bottom line: micropayments allow the music site to triple its profit margin, as compared with traditional payment methods. As for the user interface—buyers sign up for a Peppercoin account and then click on music icons to charge songs—Fisher says he's working with Peppercoin to make it "easy and hassle free." He acknowledges that it's still early, however, and that results in the next year will say more about the overall success of micropayments.

Other users go further in their praise for e-payments as enablers of new kinds of Web content. "The promised land is filled with micropayments," gushes David Vogler, a digital-entertainment executive formerly in charge of online content at Disney and Nickelodeon. One of Vogler's current ventures is a humor site called CelebrityRants.com. There, using Peppercoin's software, you can buy animated recordings of embarrassing diatribes or confessions from celebrities caught on tape—everyone from Britney Spears to new California governor Arnold

THE MICROPAYMENT MOVEMENT

COMPANY	TECHNOLOGY	MARKET/STATUS
BitPass (Palo Alto, CA)	Costs of Web content and services are deducted from an account prepaid via credit card or PayPal	Independent artists, publishers, musicians; beta trials under way; commercial release in late 2003
Firstgate Internet (Cologne, Germany)	Servers fetch Web content and deliver it to customers; charges appear on credit card or phone bill	News and analyst reports; in operation since 2000; nearly two million customers in Europe
PayLoadz (New York, NY)	Delivers digital items via e-mail after users have paid using PayPal	Electronic books, music, software; commercial release in May 2002; 9,600 sellers signed up
Paystone Technologies (Vancouver, British Columbia)	Customer accesses Web content after paying via bank account	Music, publishing; commercial release in May 2003; 700 sellers signed up
Peppercoin (Waltham, MA)	Uses statistics and encryption to process a sample of transactions; users pay via credit card once per 100 or so transactions	Music, games, publishing; commercial release in late 2003

Door to door: Scott McCloud, an author and Web artist, sells his comics using micropayments.

ALLAN PENN

Schwarzenegger. "We explored many solutions, but Peppercoin seemed like the right horse to bet on," says Vogler. Moreover, he adds, it was "insanely easy" to get the system up and running. That and a painless consumer experience seem to be the keys to early adoption.

So this is how it starts: not with a conglomerate of media giants adopting micropayments, but with pockets of small entertainment and Web-services sites. Plenty of sites will still be free, supported by advertising, says Carney. But micropayments, alongside ad sales and subscriptions, will become another leg of the stool that supports Web businesses. And micropayment companies are hoping that their systems will give entrepreneurs and consumers the freedom to try out new kinds of commerce on the Web, and to buy and sell an ever wider variety of digital goods. "The Web was dying," says Kurt Huang, CEO of BitPass, a micropayment startup he cofounded while he was a graduate student at Stanford University. "We needed to do something to change its economics."

Take Web comics. Today there are more than 3,000 online cartoonists worldwide, and that number is growing fast, says Scott McCloud, an author and Web comic artist based in Newbury Park, CA. "Micropayments are the missing piece of the puzzle," he says. Using a beta version of BitPass's technology—users prepay a few dollars into an account—McCloud sold 1,500 copies of his comics for 25 cents each in eight weeks. Not huge numbers, to be sure, but the potential for steady growth is there. And it's not supplementary income—this is how Web artists will make their money. "We're not just slapping a price tag on what could be free," says McCloud. "This is allowing us to do work that we couldn't do before."

THE COIN-OP WEB?

In the 1990s, e-payment startups like DigiCash, Flooz, and Beenz crashed because dot-com companies didn't think they needed the technology to make money, and because consumers expected Web content to be free. Times have changed, but there are still plenty of skeptics who doubt micropayments will catch on broadly, considering that MP3 listeners and Web-comics fans are the technology's main U.S. consumers so far. Even those who have made their fortunes in the online-payments world acknowledge that it's an uphill battle. "It's quite possible they could fail miserably in this economic climate," says Max Levchin, cofounder and former chief technology officer of PayPal *(see "The PayPal Precedent," p. 33)*.

But both the supply of digital content and consumers' willingness to pay for it are increasing, and the micropayment companies' strategy of signing up Web merchants, one at a time, has promise. "There will be small companies who figure out how to play this chicken-and-egg game," says Andrew Whinston, director of the Center for Research in Electronic Commerce at the University of Texas at Austin. "The key is to become successful before big companies like Microsoft get into it."

For a glimpse into the future of micropayments, look overseas. In Japan, most mobile content and services, such as cell-phone users downloading games and ring tones, are paid. And micropayments are becoming prevalent in Europe's publishing and news-media markets. Firstgate Internet, a digital content distributor in Cologne, Germany, has nearly two million customers and 2,500 clients, including British Telecommunications' Click and Buy, and it is bringing in more than $1 million a month in revenues, says founder and chairman Norbert Stangl *(see "First Out of the Gate," this page)*. Its most successful kinds of low-price content: news, research articles, and financial reports.

But Firstgate tallies each purchase separately and pays credit card fees, so its own fees are higher for merchants than most micropayment startups'. Peppercoin and BitPass hope to succeed in the U.S. market by being more efficient for small payments. So will micropayments take off here? "The truth is, nobody knows," says Guy Kawasaki, CEO of Garage Technology Ventures, a venture capital firm that is funding BitPass. "But I look around and I see 50,000 unsigned bands in the world. I see thousands of bloggers, analysts, and artists who want to publish their stuff. And how many databases would you want to search for 50 cents?" Asked when he expects to see a return on his investment, the former Apple guru laughs and says, "Before I die!"

Other observers see a clear path to adoption. "The future of micropayments is very simple," says Sun's Papadopoulos. "You'll get to a critical mass on the network. It will become the equivalent of pocket change, and you'll see fierce price competition on digital content." Falling prices, companies hope, will only increase demand. And as digital content gets cheaper, the temptation to pirate should diminish.

We're already seeing competition: last summer, the music-download store BuyMusic.com put up billboards parodying Apple's music ads and undercutting Apple's 99-cent pricing by selling songs for as little as 79 cents. With America Online, MusicMatch, and Roxio (Napster 2.0) launching stores as well, the music industry will be a proving ground—or perhaps a killing field—for e-payment technologies.

As the contest begins, most micropayment startups have enough capital to see them through the rollout phase. In September, Peppercoin announced that it had raised $4.25 million in its second round of venture funding. But in the long run, how will micropayment companies stay in business? Signing up Web merchants is fine now—deals are quick and the need is there—but an eventual goal is to hook up with a distributor that will become the eBay of bits.

So as Peppercoin makes final preparations for its commercial launch, Carney and Solomon make sales calls. Engineers sit on the edges of their seats, watching the ebb and flow of processing loads and user levels on their monitors. Rivest and Micali, ever patient, stay out of the limelight. If victory arrives, it won't come thundering out of the sky. For companies like Peppercoin, success will build up gradually, like coins clinking into a piggy bank, one by one.

Gregory T. Huang is a *Technology Review* associate editor.

FIRST OUT OF THE GATE

ANDREAS GEBAUER remembers the pesky young guy well. Five times in 2000, Firstgate Internet founder Norbert Stangl showed up at the Berlin offices of *Stiftung Warentest* (Product Testing Foundation), Germany's leading consumer reports magazine, to peddle his e-payment technology. Five times Gebauer, the magazine's online editor, said he wasn't interested. Finally, on the sixth trip, Gebauer agreed to give it a try if Stangl would just leave him alone.

Persistence pays off. "We've been very successful," says a converted Gebauer. In the three years since *Stiftung Warentest* adopted Firstgate's system, its monthly online revenues have skyrocketed from $5,000 to more than $100,000. And today, while the U.S. micropayment market is still in its early stages, Firstgate has some 2,500 merchant users and almost two million paying customers in Europe—and pulls in more than $1 million a month in revenues, making it one of the world's leading e-payment and distribution companies. Its users in media and publishing, the fastest-growing market segment, include the *Independent*, *Der Spiegel*, *Reader's Digest*, *Encyclopedia Britannica*, and Gruner and Jahr.

Firstgate's software, unlike Peppercoin's, must keep track of every transaction, and most are dollars rather than cents. But it works. Web customers can go to any Firstgate-enabled site, click on an article, and read it. They are billed via their credit card, debit card, or phone bill once they accrue a few dollars in charges. The system works by fetching digital content from Web merchants and delivering it only to paying customers. Firstgate charges a setup fee for merchants and pockets 10 to 30 percent of each transaction. (That may sound steep, but for micropayments, Firstgate can be cheaper than a credit card company.) Meticulously hand-tailored, the system has won a slew of European industry and consumer awards. "It's finely tuned, like a BMW," says Ian Price, CEO of British Telecommunications' Click and Buy division, which has partnered with Firstgate to sell online games, articles, and even a voting mechanism for interactive TV shows.

Most important, Firstgate has proven that a global market exists for Internet content priced in the $1 to $10 range, says Stangl, who is now the company's chairman. In late 2002, the company set up offices in New York. How will its success in signing up newspapers, magazines, and other media groups translate to the U.S. market? "We have experience working with so many online companies," says George Cain, Firstgate's CEO in North America. "What people are thinking about here, we've already got built into our system."

reachout

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BIG-PICTURE BIOTECH

AT SEATTLE'S INSTITUTE FOR SYSTEMS BIOLOGY, RESEARCHERS BELIEVE THAT TEASING APART COMPLICATED BIOLOGICAL NETWORKS WILL HELP UNRAVEL SOME OF MEDICINE'S GREATEST MYSTERIES. FIRST ON THE DOCKET: WHY DO INFECTIOUS DISEASES KILL SOME PEOPLE AND LEAVE OTHERS UNSCATHED, AND HOW CAN DOCTORS PROTECT THOSE WHO ARE MOST VULNERABLE?

BY JON COHEN PHOTOGRAPHS BY BRIAN SMALE

Perched to take off: Alan Aderem sees systems biology's potential to increase human life spans.

LABORATORIES AT THE Institute for Systems Biology sport magnificent views across the sailboat-cluttered waters of Lake Union, with the hilly downtown of Seattle as a backdrop. On this unusually sunny and warm June day, graced by an endless turquoise sky, the large windows provide an entrancing, even romantic, view. And it well suits the young institute, which has built itself around one of the grandest of biological visions.

Systems biology, one of the hottest fields to spring from the Human Genome Project, defies a simple description. It promises nothing less than to reshape the way that scientists think about how the human body works, providing clues to unraveling the complexities of illness and ultimately leading to new medicines to prevent and treat disease. But even the Institute for Systems Biology's Web site prominently raises the question "What is systems biology?", then offers an answer that fills six full screens of a computer monitor.

As the site struggles to explain, systems biology aspires to connect the dots of all of the body's RNA, DNA, genes, proteins, cells, and tissues, elucidating how they interact with each other to create a breathing, blood-pumping, disease-fighting, food-processing, problem-solving human. "Systems biology is a holistic view of what's going on," says Alan Aderem, cofounder and director of the institute. It looks beyond the individual actors and tries to discover the script they are following, and that marks a radical shift for biology. "The focus for the last century has been on individual molecules," says Marvin Cassman, executive director of the California Institute for Quantitative Biomedical Research, a fledgling systems biology program that joins researchers from the University of California schools at Berkeley, San Francisco, and Santa Cruz. "What's been missing is an understanding of the way individual molecules operate together."

Using this new approach, researchers have begun to address some of medicine's most basic questions: Why do some people become gravely ill from an infectious agent that only causes mild disease in most? Will a clearer picture of how immune-system cells interact with each other guide the development of new vaccines? If scientists identify a defective gene, or an aberrant protein, can they correct it without doing harm somewhere else?

Scientists have dreamed about doing systems biology for decades, but explaining the workings of even a single cell has proved too daunting. Now a confluence of developments has fundamentally altered biology. An explosion of blazingly fast, highly automated machines has enabled the analysis of biological molecules in a fraction of the time it took a mere five years ago. Similarly, the torrent of new information from the Human Genome Project and related projects that comprehensively examine entire families of such molecules has presented scientists with dizzying new "parts lists" for humans. Add in the ever increasing computational muscle of today's computers, and the systems biology approach that once seemed implausible becomes not only possible but also necessary to make sense of it all.

The formation of the Institute for Systems Biology four years ago fanned the flames, with a dozen universities and biotech firms subsequently announcing new interdisciplinary programs with a systems biology bent *(see "Other Systems-Biology Hubs," p. 48)*. But the Seattle institute remains the highest-profile player, in part because of its founders' combination of scientific expertise and machine-making prowess. It helps, too, that one of the cofounders, Leroy Hood, has something akin to celebrity status.

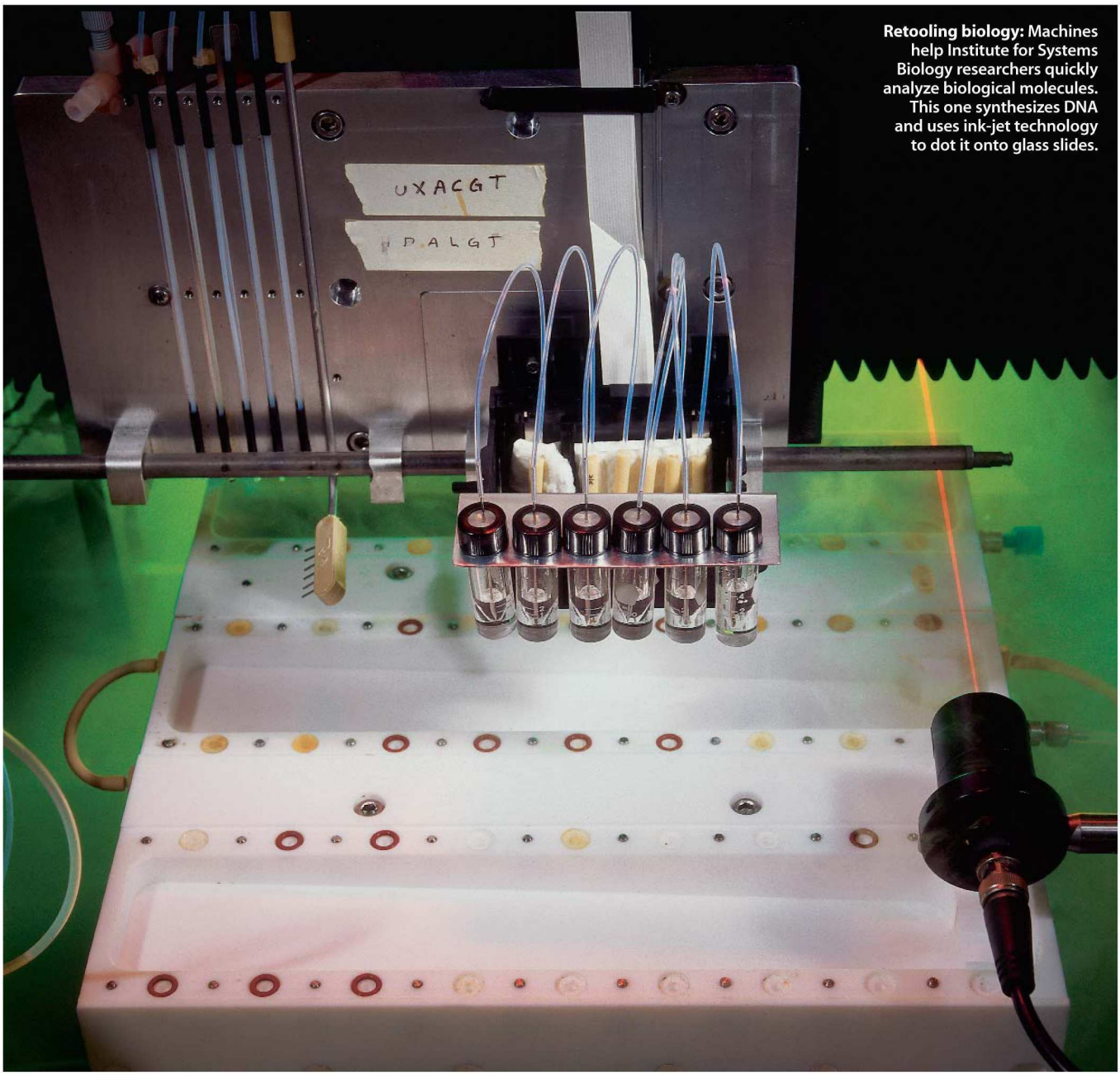
In the mid-1980s, Hood became famous in the biotech community when his lab at Caltech developed the automated DNA sequencer, a machine that made the Human Genome Project possible and helped to reconfigure biology. With support from Microsoft's Bill Gates, Hood in 1992 came to the University of Washington and started an interdisciplinary molecular biotechnology program. The program planted the seeds of systems biology, but by 1999, Hood had become frustrated with the limitations of academia, and he decided with two other researchers at the school, Aderem and Ruedi Aebersold, to start the Institute for Systems Biology. "In the end, we decided we needed more freedom, and that's why we took this pretty drastic step," says Hood. Aderem came to systems biology through a less obvious route and with a more pragmatic motivation. A pioneering immunologist, he had earned a sterling scientific reputation for his work on a single family of proteins. Still, he says, "At the end of 10 years, I was tired and realized I wouldn't live long enough to get any real understanding of a system if I was going to do it one by one."

Despite the excitement it inspires, systems biology remains very much in its infancy. The institute has so far churned out papers that begin to establish the virtues of the approach with arcane biological systems like yeast and sea urchins. But at the institute's core are far more ambitious programs in cancer, heart disease, infectious diseases, autoimmunity, and inflammation. And as they make the leap from relatively simple models to critical human problems, Aderem and his colleagues believe that their work will move medicine toward an era in which our life spans increase by 10 to 30 years. That's a terrifically bold claim. But a closer look at what Aderem and others at the institute have begun to explore shows it may be more than just a daydream inspired by the splendid view.

TESTING GROUND

A NATIVE OF SOUTH AFRICA who spent five years under house arrest for actively opposing apartheid, Aderem grows animated as he leads a tour of the institute's 6,000-square-meter lab complex, thrilling as much to the scientists themselves as to the facility's wealth of new equipment. In his baggy shorts, he looks like a safari guide as he points out a man and woman together at a microscope. "She's a cardiologist working with a physicist," he says. Aderem's lab also includes a mathematician and an engineer, in addition to the more usual assortment of biology and medical specialists. "My job is to integrate everybody," he says.

This integration of different scientific perspectives and different types of data is key to puzzling out the complexity of a network like the immune system, which is responsible for the body's exquisitely orchestrated response to microbial attack. And even with a diverse team in place, Aderem is starting with a small part of the puzzle: the various cells that make up the so-called innate immune system, the body's first line of defense. Innate immune cells are somewhat dimwitted; they have no memory and have trouble making fine distinctions between microbes. (In contrast, the acquired immune system, which includes antibodies and more troops of cells, remembers how to recognize and destroy every invader it meets.) But the innate system plays an essential role in keeping people healthy by destroying some intruders and by shuttling others to the acquired immune system.

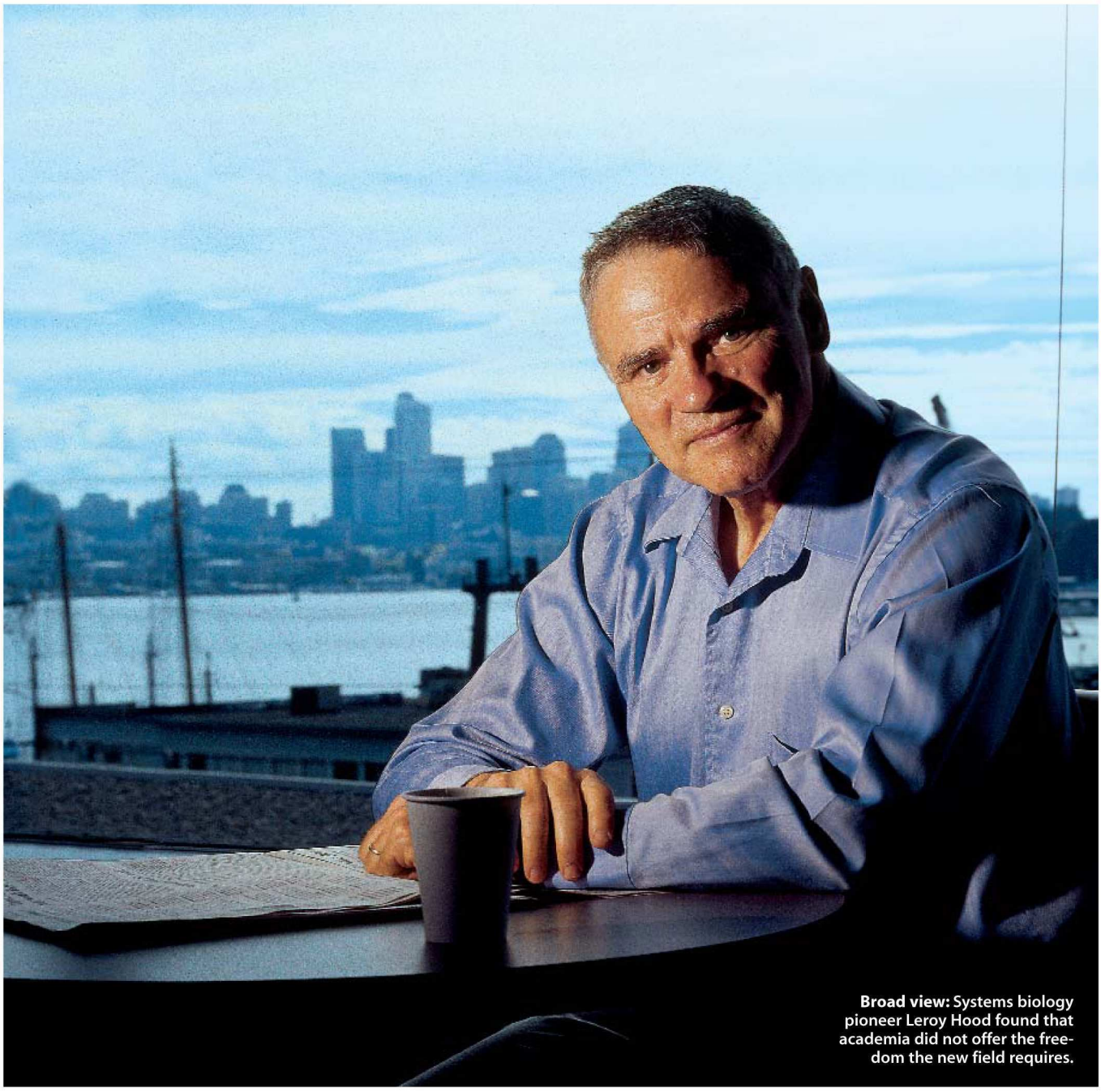


Retooling biology: Machines help Institute for Systems Biology researchers quickly analyze biological molecules. This one synthesizes DNA and uses ink-jet technology to dot it onto glass slides.

"FOR THE LAST CENTURY...WHAT'S BEEN MISSING IS AN UNDERSTANDING OF THE WAY INDIVIDUAL BIOLOGICAL MOLECULES OPERATE TOGETHER."

Because it is a relatively simple network, innate immunity makes an excellent testing ground for systems biology. In January 2003, the National Institute of Allergy and Infectious Diseases awarded a $24 million grant to the Institute for Systems Biology, Rockefeller University, and the Scripps Research Institute in La Jolla, CA, to create an "encyclopedia" of the innate immune system. Using the tools of systems biology, the researchers have started to catalogue precisely how the network reacts to microbial attack, exploring specific biochemical pathways and behaviors of genes and proteins. Compared to acquired immunity, "the players are much more well defined in innate immunity. And it will be possible to ask how important they are in the various pathways," says Richard Ulevitch, chair of immunology at the Scripps Research Institute and head of the encyclopedia project. Aderem, for instance, has long focused on one particular innate immune player, a type of white blood cell called a macrophage. "The macrophage really opens up a whole window" on systems biology, Hood says.

An early test of the macrophage-centric approach came after an unlikely event: death at a Dutch flower show. In February 1999, an annual flower show in the Netherlands attracted 77,061 visitors. Of these, 178 developed Legionnaire's disease, as did 10 exhibitors. Caused by a bacterium, Legionnaire's disease leads to severe pneumonia, which in this outbreak killed 21 people.



Broad view: Systems biology pioneer Leroy Hood found that academia did not offer the freedom the new field requires.

Dutch scientists quickly identified the likely source of the infection: a contaminated whirlpool spa on exhibit. But the outbreak raised a question that Aderem and his team thought they could help answer: why had these 188 people developed severe cases of Legionnaire's disease, while others who paused at the whirlpool exhibit had not? Aderem was certain it was not simply bad luck.

When a bug like *Legionella pneumophila* infects a person, the cellular sentinels of the innate immune system sample it and carry off pieces of it to alert the acquired immune system. That sounds simple enough, but it's actually an intricate, tangled drama that cries out for a systems biology approach. It turns out, for instance, that innate immune cells aren't quite as mindless as was once thought. Proteins called toll-like receptors, which stud the surfaces of macrophages, allow them to detect, at least on a crude level, differences between microbes. Since the discovery of the first toll-like receptor in 1997, Aderem's group has played a major role in describing how macrophages use the molecules to distinguish a virus from, say, a bacterium. "There's a bar code on the membranes of microbes that the toll-like receptors can read," says Aderem. Thanks to these bar codes, different microbes prod different toll-like receptors into action, which in turn triggers different biochemical cascades that can activate or suppress genes, cause or prevent inflammation, and steer the eventual response by the acquired immune system. If that seems complex, factor in that researchers have so far found 10 different toll-like receptors, and that the proteins work in concert. For example, three different receptors together recognize the category of bacteria that includes *Legionella pneumophila.*

Aderem's lab at the institute began its study of the Legionnaire's outbreak by hunting through thousands of blood samples to find mutated versions of one of the receptors. The task required sorting through millions of blood cells to pluck out

minute variations in the billions of DNA letters that make up each person's genome. To aid in this search, the team turned to a myriad of souped-up lab machines, many modified in-house to more quickly collect the massive amounts of data that a systems-level approach requires. Cell-sorting machines, for example, typically deposit cells on plastic plates that have 96 wells each. But the institute's sorter operates so quickly that the researchers devised a new contraption to collect the cells: a long strip of wells that spools continuously off of a reel and through the sorter.

In all, the researchers found four mutations of the targeted receptor. They then studied the DNA of people who had stopped at the contaminated whirlpool—both those who got sick and those who did not. "This was a blessed study, because we had the controls," says Aderem. Using more high-throughput tools, they hunted through the DNA samples for the mutations they had earlier identified. By comparing the gene patterns of the people who developed Legionnaire's disease and the healthy controls, they discovered that a mutant version of the receptor tripled a person's risk of getting sick. The speed with which the researchers were able to make the discovery illustrates the power of the Institute for Systems Biology's strategy. "If I had been in a genetics lab where everything was set up, I assume it would have taken many months, if not years," says Aderem. "Here, it took not more than one week." And in uncovering the mutation and linking it to a heightened risk of contracting Legionnaire's disease, they had taken a small but important step toward understanding how individual receptors and other molecules interact within the innate immune system to dramatically affect human health.

Working with pediatrician David Speert of the University of British Columbia in Vancouver, Aderem and his team hope to expand that understanding. Speert is investigating several more "experiments of nature" similar to the Netherlands flower show, with the aim of explaining how innate immunity can determine whether children get sick from infections such as tuberculosis and *E. coli*. "With every infectious disease, most people who are exposed do not become sick," says Speert. "We're trying to figure out what's different about the small percentage who get sick." Young children provide an interesting study population, he notes, because they often have not seen a particular infectious agent before and have no acquired immunity to confuse analyses of the innate system. For similar reasons, the young have the most to gain from new therapies, and unraveling how harmful microbes interact with the innate immune system could speed the development of new antimicrobial drugs and vaccines.

CONNECTING THE DOTS

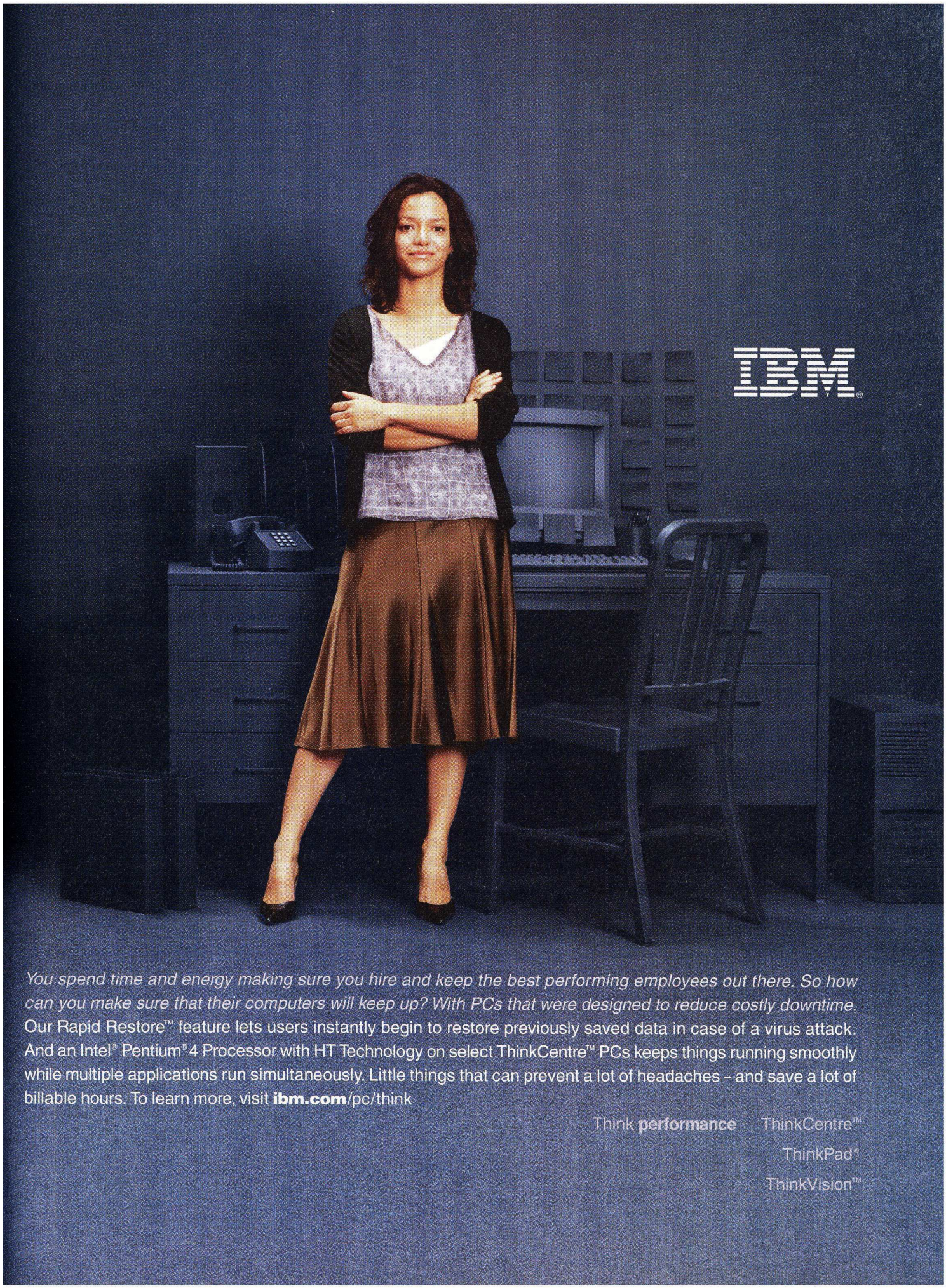
IN MANY WAYS, biology is becoming a numbers game. The human genome contains more than three billion DNA letters, representing some 40,000 genes, which actually encode untold billions of proteins, thanks to a complicated system of enzymes that slice, dice, and otherwise modify proteins as they're made. Detailed information on all these players, and on their counterparts in other organisms, is filling gargantuan databases around the world. The job of the Institute for Systems Biology is to draw connections between the data its researchers accumulate and all of the information they can scrounge from these databases and the scientific literature. It is a breathtakingly ambitious mission, marked by huge challenges in the gathering, storing, and crunching of data, so the institute has coupled its state-of-the-art computers via extremely high-bandwidth connections to machines at a supercomputing center in Fairbanks, AK, that has the capacity to store more than 300 terabytes of information.

"WITH EVERY INFECTIOUS DISEASE, MOST PEOPLE WHO ARE EXPOSED DO NOT BECOME SICK. WE'RE TRYING TO FIGURE OUT WHAT'S DIFFERENT ABOUT THE SMALL PERCENTAGE WHO GET SICK."

One homemade software program called Cytoscape helps the researchers make sense of the data. Developed collaboratively by the Institute for Systems Biology, the Whitehead Institute for Biomedical Research in Cambridge, MA, and New York's Memorial Sloan-Kettering Cancer Center, Cytoscape creates visual representations of systems. To the untrained eye, the program's collection of circles connected by lines to other circles looks like some hugely complicated engineering chart that spells out the production process at a manufacturing plant. But Aderem emphasizes that without Cytoscape, the researchers would be lost. "Humans can extract huge amounts of data, but no human can juggle more than 20 parameters," says Aderem. "By visualization, though, they can do 100,000 parameters or more."

Sitting at his computer, Aderem opens a Cytoscape representation of yeast metabolism. Although yeast metabolism offers an exceedingly simplified model of human metabolism, the same rules that control a single-celled fungus inform how the trillions of cells in a person operate. Each circle in Cytoscape, known as a node, represents a gene or protein. "If you perturb the nodes, that will result in large changes," Aderem notes. For humans, he says, "these are obvious drug targets." The visualization of the system also allows scientists to predict a medicine's side effects: if a drug interferes with a specific protein, Cytoscape shows researchers how that might have a negative effect on a connected pathway that controls such critical functions as respiration or metabolism of sugar. "This would take 15 years and billions of dollars to see in the terms of standard drug development," says Aderem.

Indeed, researchers typically spend years studying a drug in laboratory and animal experiments before moving it into cumbersome, expensive human trials, which often fail because surprising side effects suddenly surface. Such failures can cost pharmaceutical companies hundreds of millions of dollars and patients their lives. But with a detailed map of the systems that go haywire during bad drug reactions, drug companies might one day be able to substitute a quick computer analysis for many of those costly experiments.



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DREAM MACHINE

JUST AS SYSTEMS BIOLOGY aggressively strives to piece together biological networks, the Institute for Systems Biology has pieced together networks of leading scientists. And in perhaps the most intriguing joint effort to date, called the NanoSystems Biology Alliance, the institute is collaborating with leading nanotechnologists at Caltech and medical researchers at the University of California, Los Angeles. The goal is to squeeze many of the highly automated processes used in systems biology onto a one-square-centimeter silicon chip. If the NanoSystems group delivers on its promise, it will create a "nanolab," a chip that will have the power to outperform entire laboratories. In that systems biology is an approach that prizes technology that is smaller, cheaper, and faster, the nanolab is a dream machine. "It has the possibility of utterly revolutionizing systems biology," says Hood.

The researchers hope that, given just one drop of blood, the nanolab will separate thousands of cells from each other and, as Aderem says, "interrogate them individually." The soul of the new machine is an intricate network of microfluidic channels, developed by Caltech physicist Stephen Quake, that range from five to 100 micrometers wide. After being treated with labels that mark specific cell types, the blood sample enters these nanopipes, which can sort, say, macrophages from other white blood cells. Another series of nanopipes equipped with tiny detectors can then identify and separate into various channels the different proteins secreted by the macrophage.

Caltech chemist James Heath has designed one of these detection systems, an array of nanowires that he coats with molecular "hooks" to fish for proteins. Each wire, which measures a mere eight nanometers in diameter, can hook a different prey. Heath is designing the system so that only one nanowire is "live" at a time, endowing the nanolab with such exquisite sensitivity that, currently, a sample need contain only 50 to 500 molecules of a specific protein for the nanowires to detect its presence. In the future, the hooks will also be able to snare specific sequences of DNA. Meanwhile, Caltech physicist Michael Roukes and his group are making nanocantilevers that can detect protein-protein interactions, the critical interplays that determine many of the biological events in the body. Roukes attaches protein receptors to the tips of the nanocantilevers. When a specific protein binds to a receptor, it causes a tiny movement, which induces an electrical impulse that indicates both that a protein-protein dalliance has occurred and the strength of the interaction.

The alliance hopes to move the nanolab into clinical applications by working with two researchers at UCLA: Michael Phelps, who invented the positron emission tomography scan, and oncologist Charles Sawyer, a leading expert in prostate cancer. But Aderem stresses that the nanolab project remains in its infancy. "If we get this functioning in 10 years, I'd be delighted," he says.

It takes a leap of faith to think that a decade from now, a nanolab will be able to decipher from a single drop of blood what Aderem calls "the molecular fingerprint of a cell," and that this information will tie into a systems biology database that will give drugmakers and clinicians a dramatically improved ability to help people live healthier, longer lives. But great accomplishments begin with great visions, and this one has spectacular technologies behind it, the likes of which biomedicine has never seen. "When I first got into this, I felt the same way I did when we originally cloned genes," Aderem says. "'My god. The power.'"

Jon Cohen is a *Technology Review* contributing writer and author of *Shots in the Dark: The Wayward Search for an AIDS Vaccine*.

OTHER SYSTEMS-BIOLOGY HUBS

INSTITUTION/COMPANY	STRATEGY
Beyond Genomics (Waltham, MA)	Startup will use proprietary informatics technology to research new medicines for heart disease, central-nervous-system problems, and cancer
California Institute for Quantitative Biomedical Research (University of California at Berkeley, San Francisco, and Santa Cruz)	A cross-campus effort will link biology, computer science, and engineering in a multidisciplinary systems approach
Computational and Systems Biology Initiative (MIT, Cambridge, MA)	About 40 researchers from 10 disciplines will collaborate on cell death, toxicology, biochemical networks, models, tissues on a chip, and synthetic biology
Department of Systems Biology (Harvard Medical School, Boston, MA)	More than 20 faculty from biology, physics, computer science, and engineering will study networks of cells and organs to identify new approaches to treatment
Ingenuity Systems (Mountain View, CA)	Startup will use its proprietary "pathways analysis" software and database to speed drug R&D
Lewis-Sigler Institute for Integrative Genomics (Princeton University, Princeton, NJ)	Up to 15 interdisciplinary research groups will conduct basic research on the systems that control cell growth, neural circuits, synthesis of carbohydrates, and protein-protein interactions
Life Sciences Institute (University of Michigan, Ann Arbor, MI)	Up to 30 research teams will collaborate on projects that emphasize the networks that genes and proteins in a cell use to sense and adapt to stimuli
Merrimack Pharmaceuticals (Cambridge, MA)	Biotech firm will exploit "network biology" to find new drugs for cancer and autoimmune diseases
Okinawa Institute of Science and Technology (Onna Village, Okinawa, Japan)	New graduate university now being planned will emphasize integrative research in biosystems

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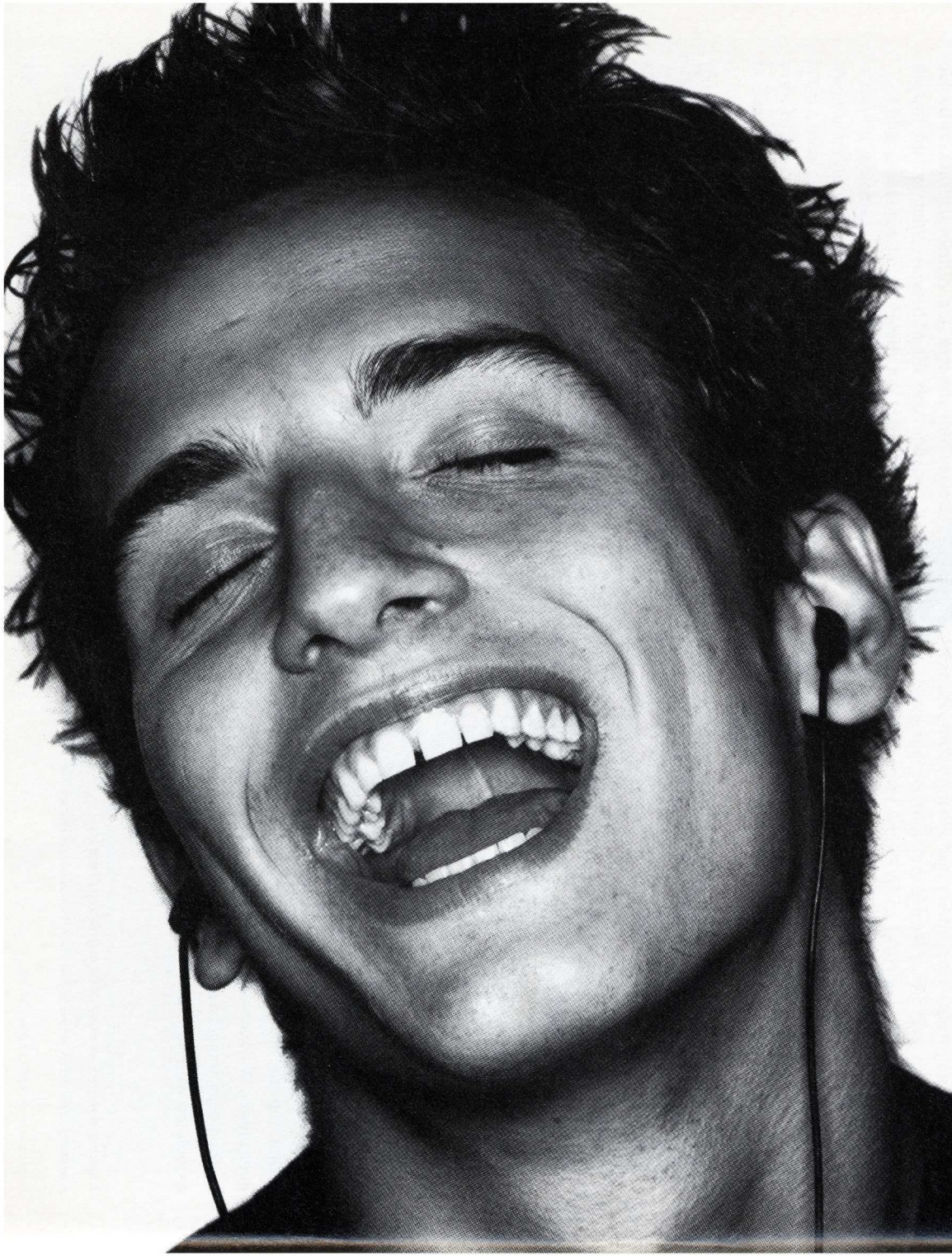

In Spain, "technology" has a capital M

Madrid is the place where Spanish creativity and advanced European technology come together. A region with state-of-the-art electronics, utilities and telecommunications industries, major investments in R&D and highly skilled professionals. Here you will find innovation, quality and competitiveness with capital letters.

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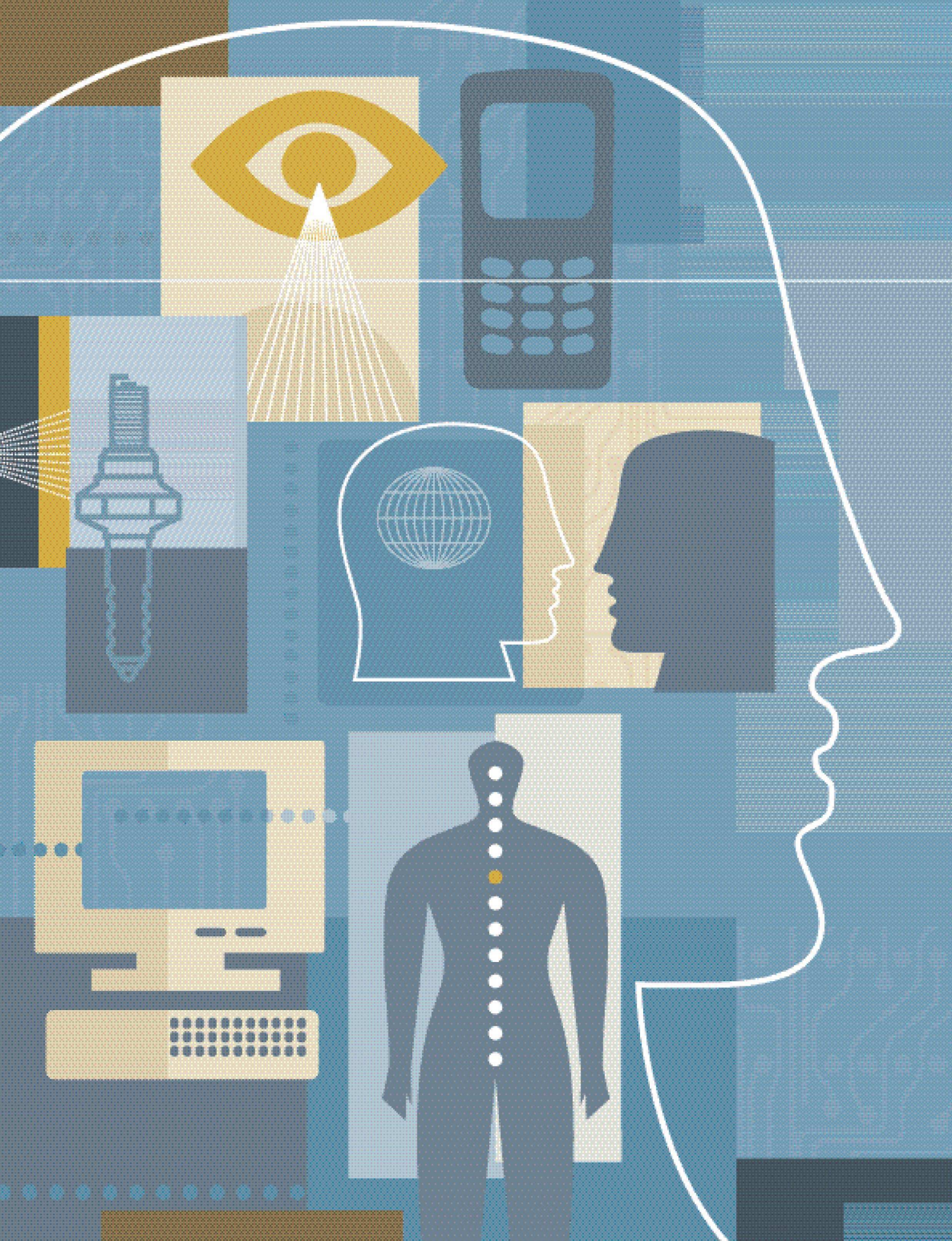
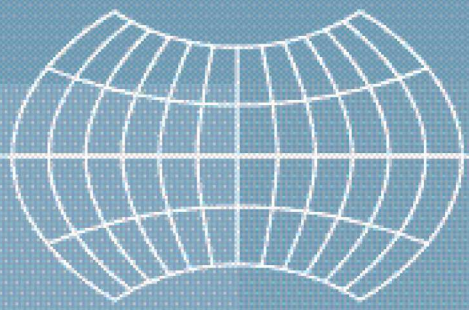
FOR MANY OF THE WORLD'S top 150 technology companies, spending on research and development continues to take a beating. A quick scan of the R&D Corporate Scorecard *(p. 59)* reveals an abundance of negative numbers, especially in electronics and telecommunications: Ericsson, Lucent, and Nortel Networks have cut budgets more than a third, while Cisco Systems is down by a quarter. The semiconductor sector is also unsteady, with Intel's and Texas Instruments' expenditures flat. ■ The good news is that R&D spending as a whole is up more than $4 billion compared to last year, with bright spots in biotech and automotive. Spending by biotech companies has more than doubled, and automakers are shelling out $5 billion more for research and development than they did last year. In fact, Ford Motor and DaimlerChrysler rank number one and two among all corporations worldwide, laying out $7.4 billion and $6.4 billion, respectively. ■ A few of the unusually large increases in spending can be attributed to acquisitions. For example, Hewlett-Packard's R&D expenditure jumped more than 53 percent after its merger with Compaq Computer in May 2002. Amgen is up 375 percent after buying Immunex in July 2002, and MedImmune shows a whopping 1,495 percent increase after its January 2002 acquisition of Aviron. ■ In total, the top 150 companies spent more than $236 billion on research and development. Ultimately, however, the success of R&D investment is best measured by the brilliant ideas coming out of corporate labs, so in "Seven Hot Projects" *(p. 52)*, *Technology Review* profiles some of the most promising technologies that will soon affect your life. ■ And while a prominent handful of companies continue their robust R&D spending, the general frugality is, some argue, beginning to hamper the innovation process. In "Our Innovation Backlog" *(p. 56)*, innovator and entrepreneur Kenan Sahin makes a strong case that although technological advances are continuing at a steady pace, there is often a failure to invest enough money to commercialize them. The result: an excess of great ideas gathering dust. Sahin lays out the problem and offers a few solutions.

INSIDE: 7 HOT PROJECTS & OUR INNOVATION BACKLOG & SCORECARD



BY ERIKA JONIETZ ILLUSTRATIONS BY PAUL WEARING



7 Hot Projects

IN INDUSTRY, research and development spans a wide range: everything from basic semiconductor physics to adding new features to products that have been on the market for years. But to get the best perspective on how the world could be different in the next few years, *Technology Review* went hunting for projects at a crucial point on that continuum: well-funded work with specific commercial goals that will, if successful, provide a dramatic improvement over the products and services now available. Some of these technologies stem from new discoveries in basic science, but others spring from new twists on old materials and techniques, or even build on years of slow progress. They are all just making their way out of the lab, and their development is motivated by strong market demands or consumer needs. *Technology Review* canvassed top corporate R&D groups worldwide in its search for these hot projects. Below are seven of the most compelling.

For most technology companies, R&D efforts represent the future of their businesses. *TR* names the most intriguing projects now nearing commercialization in corporate research labs.

Automatic speech translator

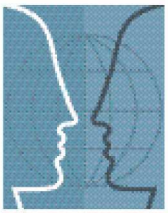
Company: IBM

Status: Could appear in laptops or personal digital assistants by mid-2004

Some social pundits claim that communication via computer has hampered personal connections. But researchers at IBM are on the verge of using computers to bring people closer together with a system that translates spoken language on the fly.

The speech-to-speech effort started a couple of years ago "as an adventurous research project," says David Nahamoo, manager of the human-language technologies group at IBM's T. J. Watson Research Center in Yorktown Heights, NY. The group has now built a working prototype: a laptop computer uses speech recognition software to process spoken words into text; sophisticated translation algorithms convert the text into a second language; and then the computer uses text-to-speech technology to "speak" the translated phrase.

So far, the prototype works only for English and Mandarin Chinese. The IBM team chose these languages in part because so many people speak them; another reason is that they represent extremes of differences in just about any linguistic parameter—for

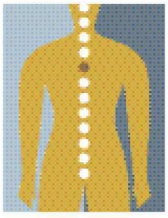


instance, in "prosody," or the meaning given to a word or sentence by the speaker's inflection. The system works with phrases likely to be used in specific situations, namely, travelers ordering in a restaurant, navigating a city, or seeking emergency medical care. Project coordinator Yuqing Gao says the laptop prototype works well enough for two people speaking different languages to carry on a rudimentary conversation. A version of the system that runs on a personal digital assistant is already in development, and though the group isn't planning work with other languages, the technology is language independent; once a need is identified, it can rapidly be applied to any pair of languages.

Spinal-cord trauma treatment

Company: Biogen

Status: Human trials anticipated within three or four years



Biologists have long known that peripheral nerves (such as those in the hands and feet) sometimes grow back after they're injured but that nerves in the spinal cord and brain do not. Now researchers are looking for a way to overcome natural inhibitions to nerve growth and help patients who have suffered spinal-cord trauma or stroke.

In the late 1990s, Yale University neurobiologist Stephen M. Strittmatter isolated a protein in the nerve cells' protective sheath that inhibits the capacity of brain and spinal-cord nerves to regenerate. Strittmatter also identified the molecule on the nerves to which this regrowth-inhibiting protein, called Nogo, binds. Since 2001, Strittmatter has been working with Biogen to find a way to block this receptor and thus allow the nerves to regrow. They have come up with several potential protein drugs, which could be injected into the spinal cord up to a week after injury and would compete with Nogo to bind to its receptor. "The challenge now is to find the best candidate molecule," says Katherine Turner, Biogen's vice president of validation biology.

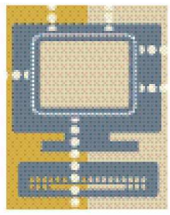
In early tests on mice and rats with spinal-cord injuries, the approach at least partially reversed paralysis. Despite these encouraging results, however, Turner cautions that most researchers don't consider mice good models for human neurological trauma. Also, it turns out there are two other proteins that bind to the receptor, and it is not yet clear whether the Nogo blockers will displace them as well—a process that may be necessary to trigger regeneration in the human spinal cord.

Blocking spam

Company: Microsoft

Status: Ready for product development

Cynthia Dwork began thinking about the problem of junk e-mail more than 10 years ago, back when most people knew "spam" only as processed meat. She came up with the idea of requiring any networked computer to solve a separate little math problem for each e-mail it sent. Proof that the problem had been solved would be attached to the e-mail, and no other computer would accept a message that did not come with this certification *(see "Making Spam Expensive,"* TR *April 2003)*. "The idea is that legitimate users will not even notice," says Andrew Goldberg, who works with Dwork at Microsoft Research. "But those sending out billions of pieces of unsolicited mail—their cost of doing business will skyrocket." Say that solving the problem takes 10 seconds for an average computer; a single computer working round the clock could send out only 8,600 messages. To stay in business, spammers would have to invest heavily in new hardware.

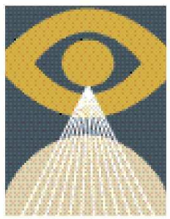


But there's a snag: users with newer, faster computers may not notice the extra computation, but those with older machines could experience serious performance lags. So Goldberg and Dwork set out with Microsoft Research colleague Ted Wobber to adapt the method so that it relies on a computer characteristic that hasn't improved as quickly as chip speed—that is, "memory latency," or the amount of time it takes for a computer's processor to fetch needed data or instructions from its memory chip. A cryptographic puzzle that is simple enough not to overtax the processor but that requires data to be retrieved from memory evens out the difference between newer and older computers. The team has demonstrated the method, which Wobber says could be built into e-mail programs such as Outlook, into e-mail servers, or into Web browsers used to send and view e-mail. To promote deployment of the technique, Microsoft is talking with computer and Internet companies to develop a standard.

Miniature ultrasound device

Company: General Electric

Status: Prototype will be under evaluation by 2005



Despite increasingly sophisticated electronics and huge improvements in image resolution, ultrasound systems today work essentially the same way they have since their introduction in the 1960s. The limitations of this method mean that small systems—and today's smallest are about half the size of a laptop computer—yield relatively low-resolution images. Kai E. Thomenius, chief technologist for ultrasound and biomedical imaging at GE Global Research, hopes to change that with a tiny revolution in the way ultrasound transducers produce and sense sound waves. His vision: "A doctor reaches into his pocket, pulls out a device, and places it on the carotid artery to see blood flow or on the heart to see its motion."

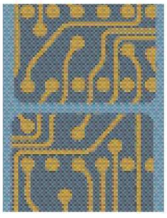
The key is replacing the materials now used in the transducers with arrays of microscopic "drumheads" made of silicon. Sound waves produced by the interaction of the ultrasound waves with the body cause these minuscule drums to vibrate, moving electric charges through the silicon. This charge is measured and translated into images. Using silicon rather than traditional piezoelectric materials that require additional electronics to interpret the sound waves means that more electronics

can be packed closer together in the transducer, yielding a more compact device. The sensitive silicon drumheads are also more responsive than the most sophisticated piezoelectrics. Moreover, the ability to integrate the transducer with the imaging electronics on silicon offers other advantages, such as the potential for the transducer to send an image wirelessly to a remote display. And while today doctors need to switch transducers to perform different kinds of ultrasound imaging, Thomenius says that a single silicon-based transducer could perform a variety of scans—from 3-D prenatal screening to scans of blood vessels.

Chip-to-chip communications

Company: Sun Microsystems

Status: Could be used in computers in five years



Silicon transistors have become so small that the limit on faster computing is no longer the number of devices that can be crammed onto a chip. Rather, it's how quickly information can move between chips. Sun Microsystems' answer to this problem: instead of connecting the chips with tiny wires, let them communicate merely by being near each other.

It's called capacitive coupling, and it works like this: Movement of a charge through a transistor on one chip creates a disturbance in the surrounding electric field. This changing field, in turn, induces an identical charge to flow through the matching transistor on the facing chip—creating what amounts to a wireless communications link over the distance of a couple of micrometers. The result is chip-to-chip communication that's up to 60 times faster than the speediest existing system's.

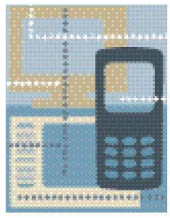
"Proximity communication is essential for the growth of computing," says Robert Drost, a Sun senior staff engineer leading the project. Supercomputers, scientific computing, Web servers, and database servers will soon demand a faster form of chip-to-chip communication, he says. Sun is developing the technology as part of an effort by the U.S. Defense Advanced Research Projects Agency to build a next-generation supercomputer in the next six years. But Drost expects the technology to begin delivering faster computing in high-end commercial systems, such as those used in scientific computers or as database servers, even sooner.

Streaming media

Company: Hewlett-Packard

Status: Large-scale tests planned in about two years

More and more people are tapping into the Internet through devices other than desktop computers: cell phones, personal digital assistants, televisions, and wireless laptops. This diversity makes life difficult for content providers transmitting multimedia files: what's good for a big-screen PC with a high-speed hookup doesn't work so well for a PDA with its small screen and slow connection.



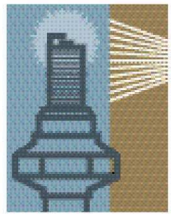
At Hewlett-Packard Labs, electrical engineers are developing ways to ensure end-to-end media delivery, regardless of the type of network or device being used. The idea is to move digital files more rapidly by adapting their transmission format to the devices that will receive them, and to position more content at the "edges" of the network—that is, close to the end user rather than the sender. The HP researchers' latest brainstorm is a series of nodes—filled with specialized routing hardware and software—that can be added to existing networks to augment the delivery of streaming media. The nodes have several functions: they move media files off individual Web servers and put them closer to users; they determine the best routes for sending files; and they detect what nearby users are watching, discern patterns in their viewing and listening preferences, and then "prefetch" data that they are likely to want. Finally, the nodes detect the kinds of devices on the receiving ends of their transmissions and adapt the media stream accordingly. That way, a high-definition TV, say, will get a high-resolution video file, while a cell phone receives a compressed file.

Prototype nodes have already been deployed between HP's various labs around the world, and on a test network connecting HP and Japanese wireless giant NTT DoCoMo. While it may take years before such systems make their way into the Internet at large, bits of the technology are starting to turn up in Web servers and software, says researcher and development manager Susie Wee.

Piezo fuel injection

Company: Siemens VDO Automotive

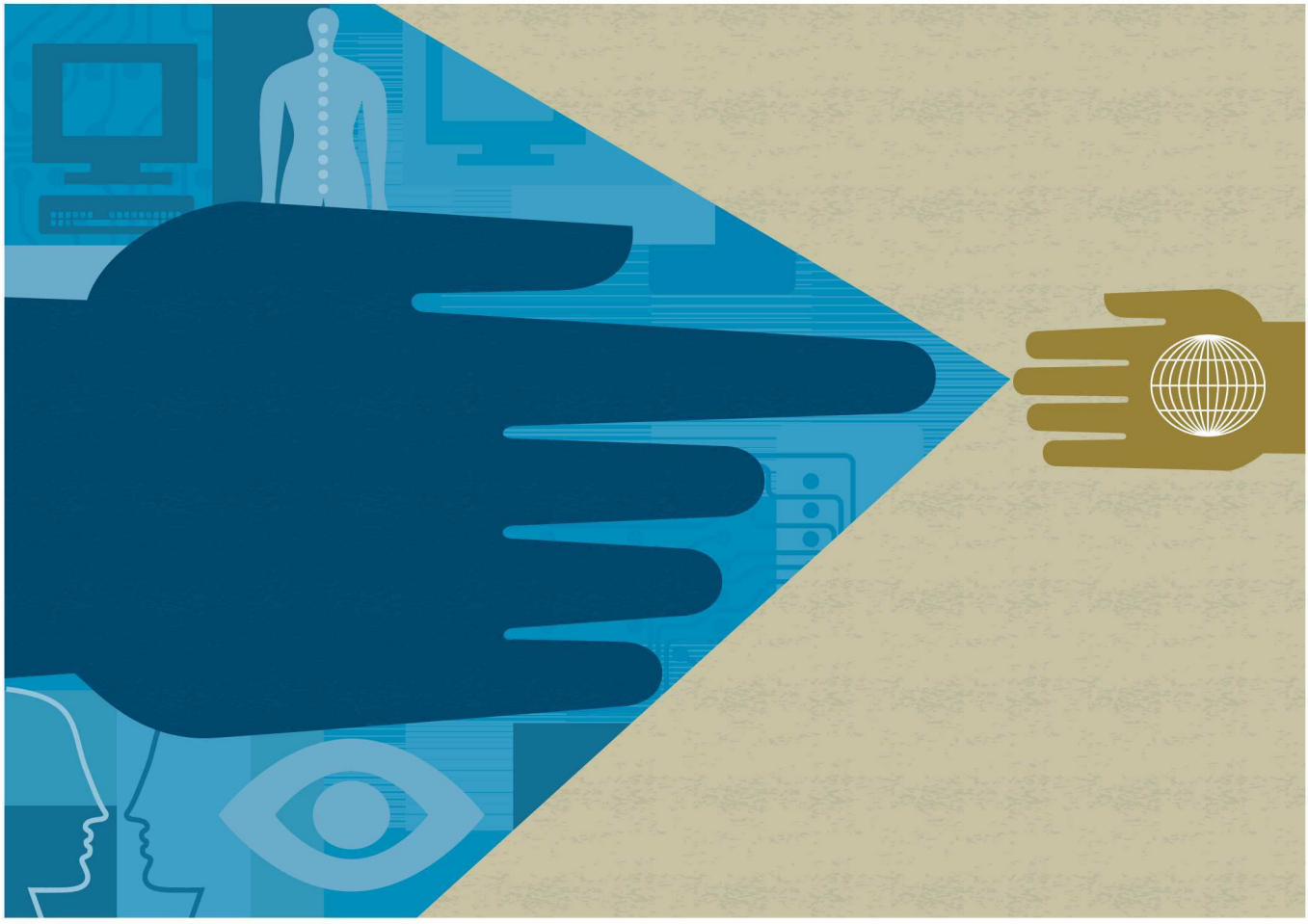
Status: In diesels now; gasoline engines by 2006



Fuel injectors transformed the automotive industry, increasing gas mileage and decreasing emissions. Researchers at Siemens VDO Automotive are set to launch another revolution in internal combustion with injection jets constructed from piezoelectric materials, which change shape in response to electrical current.

Originally developed for diesel engines popular in Europe, the jets are being adapted for gasoline engines and are expected to reduce fuel consumption by as much as 20 percent, while improving engine performance and emissions. "The piezo enables very fast, precise injection control," says Brian FitzGerald, director of Siemens Diesel Systems North America. As soon as the piezo element receives an electrical impulse, it expands, actuating the nozzle needle and opening the injection valve within two-tenths of a millisecond. The fuel is directed straight at the spark plug, rather than at the cylinder wall. Fuel ignition occurs only if the amount of fuel and the injection timing are precisely calibrated—and that's exactly what the piezo injectors, with their rapid response, excel at. Peugeot has begun incorporating the diesel version of the system into its cars in Europe, and six other manufacturers plan to follow suit. Siemens hopes piezo injection will prove as popular for gasoline engines.

Erika Jonietz is a contributing editor for *Technology Review*.



Our Innovation Backlog

BY KENAN SAHIN ILLUSTRATION BY PAUL WEARING

INNOVATION AND entrepreneurship have been a major part of my life. As a student at MIT, and later as a faculty member, I was constantly immersed in both. In 1982, I started a small software-systems development company with a $1,000 investment, entering an innovation and entrepreneurship vortex that carried me through the dot-com explosion. In 1999, Kenan Systems was purchased by Lucent Technologies, and I became an executive there, charged with advancing "Bell Labs innovation." After leaving Lucent two years later, I formed Tiax, which acquired the assets, contracts, and staff of Arthur D. Little's Technology and Innovation business, with its own legacy of helping commercialize innovations, from synthetic penicillin to advanced battery technologies.

Being part of such premier idea engines as MIT, Bell Labs, and Tiax has given me a rich perspective on the innovation landscape. What I see concerns me, because we are on the verge of losing a major source of growth. While many feel that innovation has slowed along with our economy, I perceive that the flow of new innovations has remained strong and unabated over the past few years. It's the mechanisms for implementing them that have eroded. I call the problem the innovation backlog. Unquestionably, the solutions to many current problems, the treatments for many illnesses, and the pathways to new businesses have already been invented, but they are waiting on the sidelines.

The last few decades placed a huge premium on creativity while also providing the vast financial resources needed to fund it. Despite the dot-com bust, that creative momentum continues. Through my interactions with colleagues at research universities, hospitals, and industrial labs, I have concluded that innovations are being generated at unprecedented rates.

However, it's not only innovation that matters—it's the rate at which innovations are improved and brought to market. And this has declined precipitously since the bust. The result is a surplus of innovations, with vast numbers of potentially important advances being warehoused or shelved. This situation is alarming enough in itself, but even more worrisome is the fact that innovations don't have an unlimited shelf life: they are perishable and risk becoming unusable when the people associated with them move on to other endeavors. Another reason for concern is that warehoused innovations remain untested and deprived of the iterative improvements so critical to their journey from inception to implementation.

We might have brought this problem on ourselves. In the 1980s and '90s, well over a trillion dollars went into the creation of diverse new technologies in the United States. Toward the end of that period, demand for innovations far exceeded supply—a situation that stimulated more idea generation but also escalated expectations and prices to the point that valuations of small technology companies reached untenable levels. Many acquisitions or mergers that would have created promising synergies didn't take place because of these valuation obstacles—or when they did, the price of acquisition was so high that the returns needed to justify the price were never obtained. We now seem

to face just the opposite situation, with the supply of innovations greatly outpacing demand.

This scenario has national—even global—implications. If the innovation-to-implementation flow is out of sync, the consequences for our work force, our wages, and our standard of living are serious. Unless we act decisively, it could be very difficult and costly to restart and resynchronize the flow. Before we act, however, let's consider the factors that led us to this point.

The Army of Ants

RIGHT AFTER World War II, the government and many leading companies invested heavily in research and development. The results were spectacular. Bell Labs, for example, developed the transistor, Unix, the laser, and information theory. University research, heavily funded by the government, likewise generated breakthroughs, from computers to revolutionary drugs.

But as early as 1970, the innovation flow encountered turbulence. The nation was grappling with stagflation, high unemployment, and stalled productivity, while facing stiff overseas competition, especially from Japan. These bleak circumstances led to the downsizing of most major corporations. But because of credible evidence that an R&D dollar was more productive in a small company than in a large one, interest grew in the entrepreneurial model: startups formed around core innovations and sharply focused on bringing those innovations to market. By the 1990s, after several spectacular successes, this model was attracting increasing supplies of venture capital and other funding.

The rapid spread of entrepreneurial R&D (actually, RD&D, for research, development, and delivery), coupled with downsizing, led to the disappearance of many corporate R&D labs. The ones that remained lost much of their scope. Meanwhile, the startups put their sweat equity and uninhibited creativity into developing and implementing innovation. Entrepreneurs like Bill Gates and Steve Jobs became our heroes and role models.

The analogy that comes to mind is of ants carrying one egg (one innovation) at a time—an insignificant individual feat perhaps, but one that collectively achieves a lot. Regrettably, the entrepreneurial approach to carrying innovations to market is now stalled, with many of the ants (small companies) dead; their partially implemented innovations usually died with them.

Even the startups that remain face formidable challenges. The financing supply chain is badly broken, which means that the surviving ants are slowly starving, along with their innovations. In addition, corporations that once paid premiums for startups, or their products and services, have gone conservative, hesitating to buy from struggling entrepreneurial companies.

A host of other factors makes investing in innovative products too risky. One is that in tougher times, people aren't as willing to wait the five or 10 years, or even longer, for a return on their investment that bringing an innovation to market often entails. The recent accounting scandals haven't helped, either, making executives even more averse to the risks of implementing innovation, since the bookkeeping regulations for such ventures are fuzzy at best and almost invite scrutiny.

This situation leaves us with a greatly underappreciated challenge: how to unlock the benefits stored in the increasing backlog of innovations, prevent further disruptions in the innovation-to-implementation flow, and avert the looming crisis. Efforts to meet that challenge should be undertaken at the same time that we begin documenting the extent of the innovation backlog, so that the burst of creativity that produced it isn't lost forever. I have some suggestions for how to proceed.

Adopt alternative industry models: Think of universities, research hospitals, and large corporate labs as innovation sources. They can be characterized as R&d (big research and small development) organizations. Most companies, with their marketing and production arms, would be d&D (small development, big delivery) enterprises. The lack of a strong connection between these groups is partly responsible for today's innovation backlog. Therefore, we need more "linkage" companies to bridge the gap. These are rD&d organizations. They have some research capability in order to link to the sources of innovation, and a delivery component that helps get products to market, but their main activity is in developing innovations for market.

These companies are nothing new. Sarnoff is one example, having morphed from RCA's main lab into a for-profit enterprise whose services run from contract research to collaborative R&D. I was pleased to discover that Arthur D. Little's Technology and Innovation group (not to be confused with its management consulting operations) was founded more than a century ago as just such a linkage organization as well. While synthetic penicillin was invented at MIT, the Technology and Innovation group enabled its commercialization and can boast similar successes in auto air conditioners, lithium-ion batteries, and other areas. To avert the looming innovation crisis, we need more of these companies. There is plenty of business to go around.

Loosen university intellectual-property rules: University-based research thrived in the 1980s and '90s because of extensive company sponsorships that spawned new innovations, as well as startups. That coupling is much weaker now, partly for reasons already mentioned, but also because the intellectual-property policies of universities have become so complex and money-oriented that companies find it increasingly difficult to structure deals. These restrictive policies may also cause academics to lose their entrepreneurial spirit. I suggest that universities allow faculty members to keep a much bigger share of the intellectual property they create, and also change their rules to encourage the transfer of intellectual property, focusing more on their fundamental mission than on revenue generation.

Create federal incentives: The U.S. government could create a series of incentives to encourage innovation implementation. For instance, Small Business Implementation grants could provide tax credits or other incentives to companies that license or purchase innovations and bring them to market. This would encourage implementation in much the same way that R&D credits encourage idea generation.

These are a few specific ideas for reducing the innovation backlog. But we also need a culture change. In the technology-happy 1980s and '90s, entrepreneurship centered on innovation. The founder/technologist was an entrepreneurial hero. But it has become abundantly clear that while innovation is important, it is perhaps only 5 to 10 percent of success. The other 90 to 95 percent is implementation. We need to find "implementation entrepreneurs" and make them our new heroes. TR

Kenan Sahin is the founder and president of Tiax, a collaborative-innovation firm based in Cambridge, MA.

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Corporate R&D Scorecard 2003

Technology Review's 2003 Corporate R&D Scorecard reports the annual research-and-development spending of the world's top 150 technology companies. Each company has been assigned to one of 11 sectors on the basis of its primary business. The scorecard figures are derived from annual reports and U.S. Securities and Exchange Commission filings for fiscal years ending between June 1, 2002, and May 31, 2003. Depending on when each company's fiscal year ends, its most recent filings could be designated either fiscal year 2002 or fiscal year 2003. To avoid confusion, therefore, we label our figures as being from a company's "Latest Year." A more extensive list of companies is available on the Web at www.technologyreview.com/scorecards.

		R&D SPENDING (IN MILLIONS)†			REVENUE (IN MILLIONS)		R&D SPENDING AS % OF REVENUE		NUMBER OF EMPLOYEES	R&D SPENDING PER EMPLOYEE (IN $$)	
	COMPANY	LATEST YEAR*	RANK	% CHANGE FROM PREVIOUS YEAR††	LATEST YEAR*	% CHANGE FROM PREVIOUS YEAR	LATEST YEAR*	RANK	LATEST YEAR*	LATEST YEAR*	RANK
Aerospace	BAE Systems (U.K.)	2,552	1	-8.2	12,855	-10.7	19.8	1	68,100	37,468	1
	EADS (Netherlands)	2,224	2	2.4	31,720	-2.9	7.0	2	103,967	21,387	2
	Boeing (U.S.)	1,639	3	-15.3	54,069	-7.1	3.0	7	165,000	9,933	4
	United Technologies (U.S.)	1,191	4	-5.0	28,215	1.1	4.2	4	155,000	7,684	5
	Honeywell International (U.S.)	757	5	-9.0	22,274	-5.8	3.4	6	108,000	7,009	7
	Rolls-Royce (U.K.)	473	6	-17.0	9,213	-8.5	5.1	3	39,200	12,060	3
	Thales (France)	456	7	-0.5	11,781	8.2	3.9	5	60,662	7,522	6
	Raytheon (U.S.)	449	8	-5.5	16,760	4.6	2.7	8	76,400	5,877	8
	Northrop Grumman (U.S.)	406	9	18.7	17,206	32.2	2.4	9	117,300	3,461	9
Automotive	Ford Motor (U.S.)	7,700	1	4.1	162,586	1.1	4.7	6	350,321	21,980	3
	DaimlerChrysler (Germany)	6,440	2	2.3	158,685	-2.2	4.1	9	370,677	17,375	6
	General Motors (U.S.)	5,800	3	-6.5	186,763	5.4	3.1	14	350,000	16,571	8
	Toyota Motor (Japan)	5,605	4	13.3	133,992	6.3	4.2	8	264,096	21,225	4
	Honda Motor (Japan)	3,646	5	10.5	66,532	8.3	5.5	3	126,900	28,732	1
	Volkswagen (Germany)	3,067	6	8.7	92,239	-1.8	3.3	11	324,892	9,440	12
	Nissan Motor (Japan)	2,507	7	14.6	56,993	10.2	4.4	7	119,988	20,891	5
	BMW (Germany)	2,133	8	20.9	44,855	9.9	4.8	5	94,710	22,525	2
	Peugeot (France)	1,978	9	7.6	57,929	5.3	3.4	10	198,600	9,962	10
	Fiat (Italy)	1,854	10	n/a	58,800	-3.7	3.2	12	186,492	9,943	11
	Delphi Automotive Systems (U.S.)	1,700	11	0.0	27,427	5.1	6.2	2	192,000	8,854	13
	Denso (Japan)	1,526	12	-1.5	19,470	-2.8	7.8	1	89,380	17,078	7
	Renault (France)	1,213	13	-40.9	38,547	0.0	3.1	13	140,417	8,635	14
	Visteon (U.S.)	902	14	-19.4	18,395	3.1	4.9	4	77,000	11,714	9
Biotech	Amgen (U.S.)	4,108	1	375.0	5,523	37.5	74.4	6	10,100	406,772	3
	MedImmune (U.S.)	1,323	2	1,494.8	848	37.0	156.1	5	1,605	824,592	1
	Millennium Pharmaceuticals (U.S.)	753	3	88.0	353	43.4	213.4	4	2,079	362,294	4
	Genentech (U.S.)	599	4	16.0	2,618	25.8	22.9	13	5,252	114,132	8
	Applera (U.S.)	483	5	49.4	1,701	3.5	28.4	10	6,000	80,514	10
	Chiron (U.S.)	371	6	7.7	1,172	10.9	31.7	8	4,044	91,734	9
	Biogen (U.S.)	368	7	16.9	1,148	10.2	32.0	7	2,633	139,600	7
	Serono (Switzerland)	358	8	16.0	1,423	13.9	25.2	11	4,616	77,578	11
	Genzyme (U.S.)	310	9	-13.7	1,329	8.7	23.3	12	5,600	55,423	13
	OSI Pharmaceuticals (U.S.)	232	10	314.7	22	-16.2	1,065.3	2	429	541,730	2
	Human Genome Sciences (U.S.)	191	11	30.7	4	-72.2	5,357.7	1	1,086	176,024	6
Chemicals	Bayer (Germany)	2,686	1	1.8	30,720	0.1	8.7	3	122,600	21,909	4
	DuPont (U.S.)	1,264	2	-20.4	24,006	-2.9	5.3	7	79,000	16,000	8
	BASF (Germany)	1,204	3	-9.0	34,176	-0.9	3.5	10	89,389	13,473	10
	Dow Chemical (U.S.)	1,066	4	-6.6	27,609	-1.7	3.9	9	49,959	21,338	5
	Akzo Nobel (Netherlands)	967	5	7.7	14,854	-0.8	6.5	6	67,900	14,249	9
	Mitsubishi Chemical (Japan)	760	6	7.6	15,753	6.0	4.8	8	37,633	20,191	6
	Syngenta (Switzerland)	697	7	-3.6	6,197	-2.0	11.2	2	22,791	30,582	3
	Merck (Germany)	645	8	5.4	7,928	-0.7	8.1	4	34,504	18,699	7
	Sumitomo Chemical (Japan)	608	9	9.2	9,274	9.1	6.6	5	17,906	33,943	2
	Monsanto (U.S.)	527	10	-5.9	4,673	-14.4	11.3	1	13,700	38,467	1
Computers (hardware)	IBM (U.S.)	4,754	1	2.9	81,186	-2.3	5.9	10	315,889	15,050	10
	Hewlett-Packard (U.S.)	4,105	2	53.7	56,588	25.1	7.3	6	141,000	29,113	5
	Toshiba (Japan)	2,767	3	1.6	47,204	4.9	5.9	9	165,776	16,689	8
	NEC (Japan)	2,472	4	-11.2	39,186	-8.0	6.3	7	145,807	16,957	7
	Fujitsu (Japan)	2,385	5	-18.3	38,539	-7.8	6.2	8	157,044	15,186	9
	Canon (Japan)	1,950	6	6.9	24,539	1.1	7.9	4	97,802	19,941	6
	Sun Microsystems (U.S.)	1,835	7	-12.3	12,496	-31.5	14.7	1	39,400	46,574	1
	Mitsubishi Electric (Japan)	1,498	8	-12.3	30,372	-0.3	4.9	12	110,279	13,585	11
	Xerox (U.S.)	917	9	-8.0	15,849	-6.8	5.8	11	67,800	13,525	12
	EMC (U.S.)	781	10	-15.9	5,438	-23.3	14.4	2	17,400	44,911	2
	Ricoh (Japan)	697	11	3.4	14,509	3.9	4.8	13	74,607	9,347	13
	Apple Computer (U.S.)	447	12	1.4	5,742	7.1	7.8	5	12,241	36,517	3
	Maxtor (U.S.)	401	13	-24.5	3,780	0.4	10.6	3	12,449	32,213	4
	Dell (U.S.)	319	14	-0.6	35,404	13.6	0.9	14	39,100	8,159	14
Computers (software)	Microsoft (U.S.)	4,307	1	-1.6	28,365	12.1	15.2	8	50,500	85,287	2
	Oracle (U.S.)	1,180	2	9.7	9,475	-2.0	12.5	9	40,650	29,028	10
	SAP (Germany)	965	3	1.2	7,864	1.0	12.3	10	28,410	33,957	9
	Computer Associates International (U.S.)	664	4	-2.1	3,116	5.1	21.3	5	16,000	41,500	8
	BMC Software (U.S.)	502	5	4.7	1,327	3.1	37.8	1	6,861	73,153	4
	Automatic Data Processing (U.S.)	475	6	-7.7	9,771	3.2	4.9	12	40,000	11,871	12
	Avaya (U.S.)	459	7	-19.2	4,956	-27.0	9.3	11	18,800	24,415	11
	Electronic Arts (U.S.)	401	8	3.4	2,482	43.9	16.2	7	4,000	100,248	1
	Cadence Design Systems (U.S.)	373	9	15.9	1,293	-9.6	28.9	3	5,175	72,091	5
	Siebel Systems (U.S.)	366	10	84.4	1,635	-21.6	22.4	4	5,909	61,978	6
	PeopleSoft (U.S.)	353	11	16.0	1,949	-8.0	18.1	6	8,293	42,526	7
	Synopsys (U.S.)	313	12	65.0	907	33.2	34.6	2	4,254	73,635	3

Drugs/Medical										
Pfizer (U.S.)	5,176	1	6.8	32,373	12.2	16.0	6	98,000	52,816	4
GlaxoSmithKline (U.K.)	4,616	2	9.4	33,764	3.5	13.7	11	106,166	43,479	10
Johnson and Johnson (U.S.)	4,146	3	12.2	36,298	12.3	11.4	15	108,300	38,283	14
Aventis (France)	3,628	4	-1.8	21,877	-10.1	16.6	4	78,099	46,455	8
Novartis (Switzerland)	3,097	5	3.6	23,133	1.2	13.4	12	72,877	42,494	11
AstraZeneca (U.K.)	3,069	6	10.7	17,841	8.3	17.2	3	58,700	52,283	5
Roche (Switzerland)	3,038	7	9.4	21,216	1.9	14.3	8	69,659	43,617	9
Merck (U.S.)	2,677	8	9.0	51,790	8.5	5.2	18	77,300	34,634	16
Bristol-Myers Squibb (U.S.)	2,387	9	-51.8	18,119	0.3	13.2	13	44,000	54,250	3
Eli Lilly (U.S.)	2,233	10	-7.9	11,078	-4.0	20.2	1	43,700	51,105	6
Wyeth (U.S.)	2,080	11	11.3	14,584	4.3	14.3	9	52,762	39,426	13
Abbott Laboratories (U.S.)	1,669	12	-42.6	17,685	8.6	9.4	17	71,819	23,246	18
Schering-Plough (U.S.)	1,425	13	8.6	10,180	4.3	14.0	10	30,500	46,721	7
Sanofi-Synthelabo (France)	1,292	14	18.1	7,901	14.8	16.4	5	32,436	39,836	12
Takeda Chemical (Japan)	1,037	15	23.9	8,731	4.1	11.9	14	14,547	71,276	1
Schering (Germany)	1,005	16	9.6	5,329	3.7	18.9	2	26,245	38,279	15
Medtronic (U.S.)	864	17	-8.1	7,665	19.6	11.3	16	29,581	29,194	17
Sankyo (Japan)	723	18	6.2	4,757	3.8	15.2	7	11,626	62,214	2
Electrical/Electronics										
Siemens (Germany)	6,173	1	-14.2	89,128	-3.4	6.9	8	426,000	14,491	10
Matsushita Electric Industrial (Japan)	4,599	2	-2.6	61,776	7.6	7.4	7	288,324	15,951	9
Motorola (U.S.)	3,766	3	-13.6	26,679	-10.7	14.1	4	97,000	38,825	3
Sony (Japan)	3,698	4	2.3	62,376	-1.4	5.9	10	161,100	22,957	7
Philips Electronics (Netherlands)	3,241	5	-7.8	33,756	-1.6	9.6	6	170,087	19,054	8
Hitachi (Japan)	3,148	6	-9.2	68,370	2.5	4.6	14	320,528	9,821	12
Agilent Technologies (U.S.)	1,169	7	-13.3	6,010	-28.4	19.5	1	36,000	32,472	4
Sharp (Japan)	1,120	8	6.5	16,719	11.1	6.7	9	46,633	24,016	6
Sanyo Electric (Japan)	1,008	9	12.9	18,978	7.7	5.3	11	79,025	12,762	11
Emerson Electric (U.S.)	530	10	-10.8	13,824	-10.7	3.8	15	111,500	4,753	17
Marconi (U.K.)	520	11	-47.9	3,187	-53.6	16.3	2	21,000	24,786	5
Schneider Electric (France)	501	12	-7.8	9,612	-7.8	5.2	12	74,814	6,703	14
Matsushita Electric Works (Japan)	461	13	-1.2	9,808	-2.0	4.7	13	48,091	9,590	13
Qualcomm (U.S.)	452	14	8.9	3,040	13.4	14.9	3	8,100	55,763	1
Tokyo Electron (Japan)	418	15	-6.9	3,844	10.2	10.9	5	10,053	41,612	2
Sumitomo Electric (Japan)	406	16	0.4	12,427	0.3	3.3	17	79,197	5,126	16
Thomson Multimedia (France)	397	17	1.6	10,807	-2.9	3.7	16	65,487	6,059	15
Tech Conglomerates										
General Electric (U.S.)	2,215	1	11.9	130,685	4.0	1.7	7	315,000	7,032	5
Fuji Photo Film (Japan)	1,328	2	8.3	20,913	4.4	6.4	3	72,633	18,284	1
3M (U.S.)	1,070	3	-1.3	16,332	1.7	6.6	2	68,774	15,558	2
Eastman Kodak (U.S.)	762	4	-2.2	12,835	-3.0	5.9	4	70,000	10,886	4
Tyco International (Bermuda)	633	5	10.7	35,644	-1.1	1.8	6	267,500	2,368	7
ABB (Switzerland)	550	6	-15.9	18,295	-22.9	3.0	5	139,051	3,955	6
ITT (U.S.)	519	7	22.2	4,985	6.6	10.4	1	38,000	13,661	3
Semiconductors										
Intel (U.S.)	4,054	1	1.5	26,764	0.8	15.1	16	78,700	51,512	8
Texas Instruments (U.S.)	1,619	2	1.3	8,383	2.2	19.3	12	34,589	46,807	11
Infineon Technologies (Germany)	1,124	3	-10.8	5,524	-8.2	20.4	11	30,180	37,260	14
Applied Materials (U.S.)	1,060	4	-12.3	5,062	-31.1	20.9	10	16,077	65,949	6
STMicroelectronics (Netherlands)	1,022	5	4.5	6,270	-0.5	16.3	14	43,170	23,674	17
Advanced Micro Devices (U.S.)	816	6	25.4	2,697	-30.7	30.3	3	12,146	67,192	5
Micron Technologies (U.S.)	561	7	14.7	2,589	-34.2	21.7	8	18,700	30,016	16
LSI Logic (U.S.)	519	8	-23.5	1,817	1.8	28.5	4	5,281	98,196	3
National Semiconductor (U.S.)	436	9	-1.4	1,673	11.9	26.1	6	9,800	44,520	13
Analog Devices (U.S.)	424	10	-10.6	1,708	-25.0	24.8	7	8,600	49,287	10
Conexant Systems (U.S.)	324	11	-33.0	602	-29.0	53.8	1	2,460	131,630	2
ASML (Netherlands)	317	12	-26.9	2,078	6.2	15.2	15	5,971	53,016	7
Cypress Semiconductor (U.S.)	290	13	-0.2	775	-5.4	37.4	2	4,101	70,733	4
KLA-Tencor (U.S.)	287	14	-19.4	1,637	-22.2	17.6	13	5,700	50,422	9
Maxim Integrated Products (U.S.)	276	15	-1.7	1,025	-35.0	26.9	5	6,067	45,417	12
Rohm (Japan)	266	16	48.4	2,924	9.0	9.1	18	16,841	15,773	18
Nvidia (U.S.)	260	17	69.1	1,869	36.5	13.9	17	1,513	172,036	1
Atmel (U.S.)	253	18	-5.6	1,194	-18.9	21.2	9	7,550	33,532	15
Telecommunications										
Cisco Systems (U.S.)	3,513	1	-26.5	18,915	-15.2	18.6	10	36,000	97,583	3
Ericsson (Sweden)	3,399	2	-37.1	16,892	-37.1	20.1	7	64,621	52,596	9
Nippon Telegraph and Telephone (Japan)	3,305	3	1.3	91,167	-6.5	3.6	14	207,363	15,937	15
Nokia (Finland)	3,238	4	2.2	31,842	-3.8	10.2	13	51,748	62,567	7
Alcatel (France)	2,361	5	-22.4	17,554	-34.7	13.5	12	75,940	31,096	12
Lucent Technologies (U.S.)	2,310	6	-34.4	12,321	-42.1	18.7	9	47,000	49,149	11
Nortel Networks (Canada)	2,281	7	-35.0	11,155	-40.4	20.4	6	36,960	61,713	8
Matsushita Communication (Japan)	1,258	8	9.9	6,542	-26.1	19.2	8	16,685	75,382	4
NTT DoCoMo (Japan)	1,054	9	25.8	40,138	-7.0	2.6	16	20,792	50,670	10
Broadcom (U.S.)	714	10	-18.7	1,083	12.6	65.9	2	2,508	284,756	1
Agere Systems (U.S.)	693	11	-27.1	2,177	-46.6	31.8	3	10,700	64,766	6
Alstom (France)	660	12	8.1	22,650	-9.0	2.9	15	109,671	6,017	16
France Telecom (France)	611	13	1.6	49,467	8.4	1.2	18	240,145	2,545	20
BT Group (U.K.)	605	14	5.0	29,808	-8.9	2.0	17	104,700	5,777	17
Corning (U.S.)	483	15	-23.5	3,164	-47.7	15.3	11	23,200	20,819	14
Tellabs (U.S.)	341	16	-19.9	1,317	-40.1	25.9	4	4,828	70,547	5
JDS Uniphase (U.S.)	280	17	-61.0	1,098	-66.0	25.5	5	9,222	30,373	13
Vodafone Group (U.K.)	261	18	382.4	48,349	33.0	0.5	20	66,667	3,916	18
Ciena (U.S.)	255	19	-14.8	361	-77.5	70.7	1	2,118	120,534	2
AT&T (U.S.)	254	20	-21.8	37,827	-10.4	0.7	19	71,000	3,577	19

*Data are for fiscal years ending between June 1, 2002, and May 31, 2003
†R&D spending may include R&D acquired while in process
††Figures may be affected by acquisitions and divestitures and may also reflect changes in R&D Scorecard reporting methodologies
Source: Standard and Poor's

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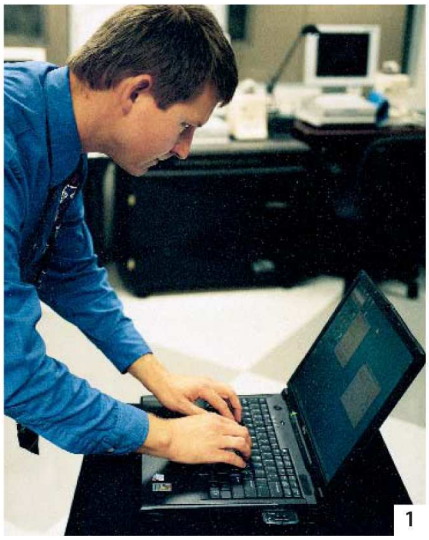
WIRELESS FOR THE DISABLED

Mathematician and computer scientist John Peifer and his team at the Georgia Institute of Technology are adapting wireless technology to aid millions of disabled people worldwide.

Photographs by Beth Perkins

THE WIRELESS EXPLOSION has made cell phones, personal digital assistants, and other devices ubiquitous and has changed the way people communicate and work. It also offers the possibility of changing the lives of disabled people, by helping them overcome or cope with their impairments. The 25 researchers at the Rehabilitation Engineering Research Center on Mobile Wireless Technologies for Persons with Disabilities at the Georgia Institute of Technology have made it their mission to realize that possibility. The center is designing wireless aids that target a variety of disabilities, including mobility, vision, and hearing impairments. The researchers use off-the-shelf components to build these systems "so that they're affordable and available," says John Peifer, the center's codirector. The center is also trying to influence wireless-device manufacturers to make their existing products more accessible to people with disabilities and to adopt new applications with the needs of the disabled in mind. "Mobile wireless is going to be a big part of the future. There's a concern that people with disabilities would be left out," says Peifer. He and his colleagues showed *Technology Review* associate editor Corie Lok a few of their prototypes.

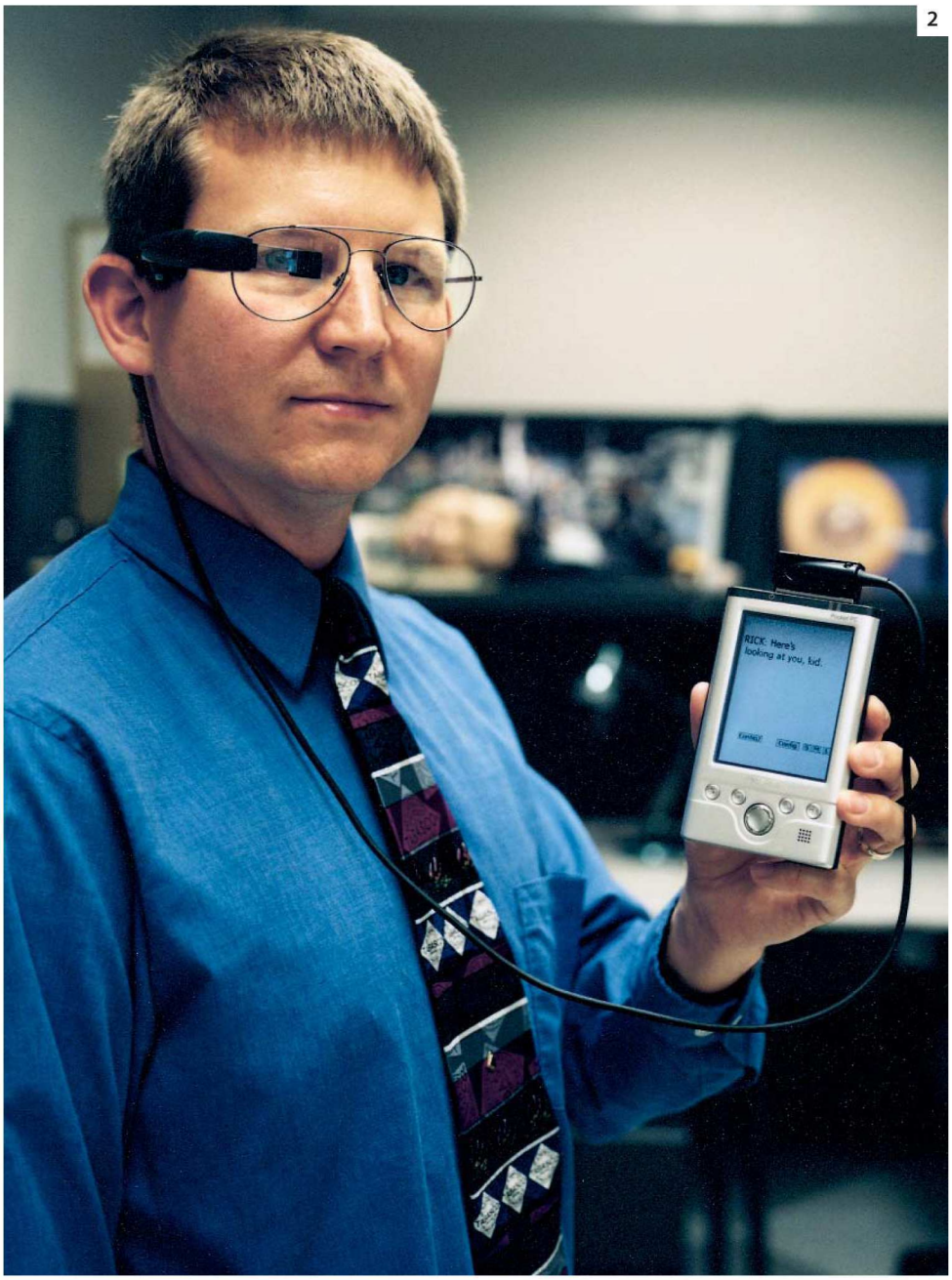
Paving the way: John Peifer helps lead an effort to build wireless aids for people dealing with vision, hearing, and other impairments.



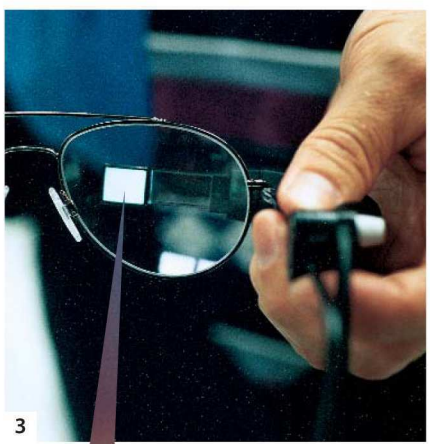
WEARABLE CAPTIONING

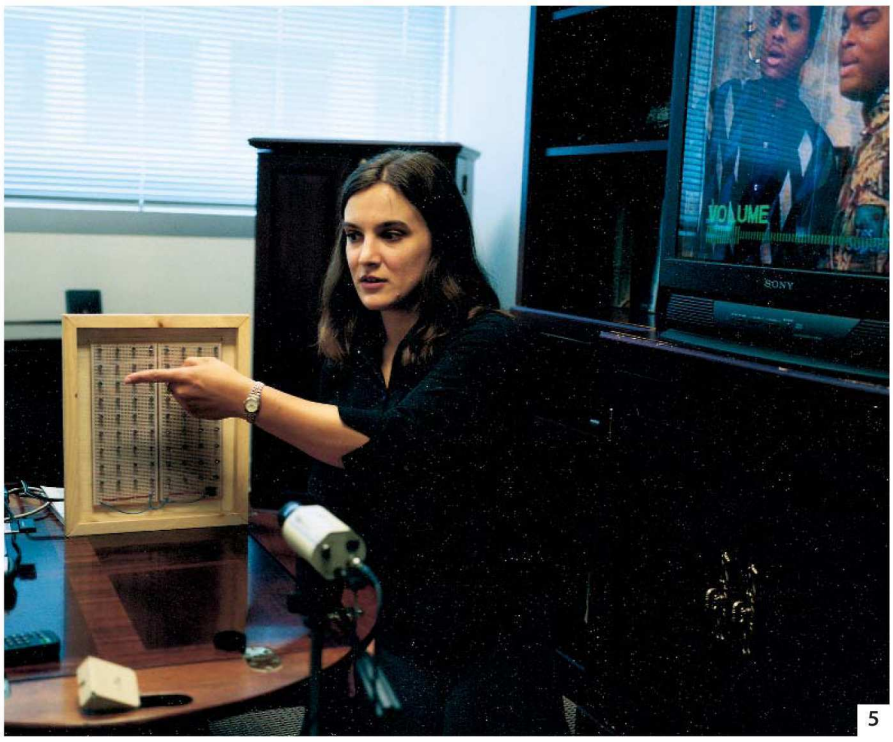
1. Research scientist Jack Wood starts by demonstrating a personal captioning device that could be worn by a hearing-impaired person in a movie theater, lecture hall, or meeting room. The system would make it possible for the user to follow along in real time when a sign-language translator wasn't available. "The venue would possess some sort of transmitter," to wirelessly beam captions to the user, Wood says. "Today that's being represented by a wireless-enabled laptop." He enters text into the computer as a stenographer might in a lecture hall; further down the road, speech-to-text software might be used to automatically convert a speaker's words to captions in real time. In a movie theater, the system would draw on the captions that normally come prepackaged with films, but which usually aren't displayed at public venues.

2. As the captions are being entered, the transmitter sends them to a PDA carried by the user. "We went with a PDA, because this way users can either use their own, go out and buy their own, or it's something cheap enough that the venues can buy and check it out to patrons," says Wood. The user can read the text right off the PDA screen or off of a 30-gram, commercially available mini monitor that clips on to his or her glasses.



3-4. With the mini monitor, the user can keep an eye on the action and read the captions at the same time. The captions, which take up only a small portion of the user's field of vision, appear to be floating in between the eye and what the user is looking at. Wood and his colleagues are looking for a company to commercialize this system. "The idea is that the company would license the technology and incorporate it into their own product line," says Peifer.





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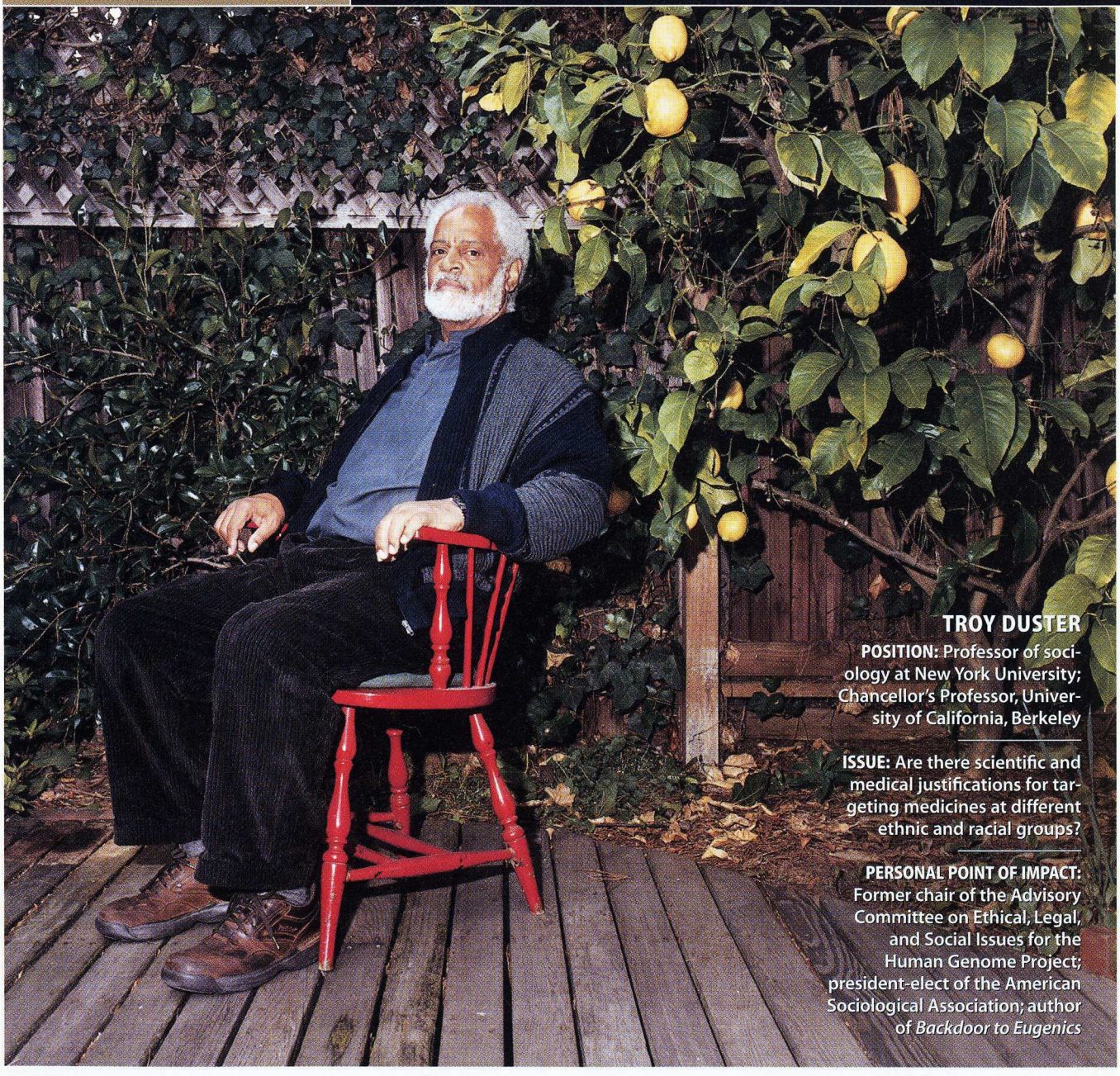
6

REMOTE GESTURE CONTROL

5. Down the hallway, Tracy Westeyn, a PhD student, has another prototype set up in a mock living room. She is working on a "gesture panel" that would allow a person who lacks the fine motor control necessary for manipulating small switches and buttons to control devices around the house with a simple wave of the hand. She demonstrates the idea by turning up the volume on the TV behind her. All it takes is moving a pointed finger upwards in front of the panel, which bears a grid of 72 infrared light-emitting diodes. A camera pointed at the panel detects breaks in the infrared beams as Westeyn's hand passes by and feeds the information to a laptop computer. The computer recognizes the gesture and translates it into a specific control command for a device—in this case the volume control for the TV—and can send the command via infrared or radio signals to the device. One of Westeyn's colleagues is working on another gesture-based system that can recognize sign language. "This could provide automatic translation for people who don't understand sign language," says Peifer.

AUDIO NAVIGATOR

6. The next stop on the tour is a visit with research scientist Jeff Wilson, who is working on a system that uses sound to guide blind people. Wilson dons a pair of headphones and a black bag that holds a wireless computer, which he controls via an attached handheld device. A GPS sensor on the bag's shoulder strap and a head-tracking sensor atop the headphones help the computer keep tabs on his position and orientation. To guide him along a pre-programmed route, the computer plays beeps over the headphones, modulating them so that the sound appears to be coming from one direction or another. Wilson follows the route by simply moving toward the apparent source of the sound. Using the computer and sensors, he can also "record" a new path as he walks. "This has great potential to help blind people get around and be more independent," says Peifer. Assessing the center's work as a whole, Peifer says he is optimistic that wireless technology can profoundly affect the lives of disabled people. "The technology now makes it possible for them to do things they couldn't do before," he says.



TROY DUSTER

POSITION: Professor of sociology at New York University; Chancellor's Professor, University of California, Berkeley

ISSUE: Are there scientific and medical justifications for targeting medicines at different ethnic and racial groups?

PERSONAL POINT OF IMPACT: Former chair of the Advisory Committee on Ethical, Legal, and Social Issues for the Human Genome Project; president-elect of the American Sociological Association; author of *Backdoor to Eugenics*

Race in Medicine

BY DAVID ROTMAN | Photograph by James Smolka

TECHNOLOGY REVIEW: As researchers begin to better understand the genetic differences between populations, some are advocating using that information to develop and justify treatments and even particular medicines that target specific racial groups. Is this a good idea?

TROY DUSTER: There's not a quick and easy answer. I think under certain conditions, in certain contexts, race can be a proxy for looking at other factors. For example, we know that sickle cell anemia in this country is related to race because Americans of West African descent are at much higher risk. Where there are limited funds for a full-population screen, it would be legitimate to set up a screening program that is race related. But that is different than saying we're going to deliver a drug to a population defined by race. I think it is a mistake to begin with the assumption that race is a sufficiently precise category to deliver pharmaceuticals. Race is a huge and crude category with so much genetic variation that the idea of trying to come up with a drug specifically designed for such a population is counterintuitive and probably empirically wrong.

TR: And yet it is something being talked about by some drug companies.

DUSTER: Yes, I think it is because of prof-

its and markets. Pharmaceutical companies don't sell drugs to individuals; they sell drugs to markets. So part of what is going on here is a market-driven biotechnology which is trying to find a population base for its product.

TR: But as you said, there are no easy answers. Are there potential benefits in looking at genetic-based medical differences between various population groups?
DUSTER: It is perfectly legitimate to ask why the rate of prostate cancer is more than double for group A than group B. And when that group A happens to be blacks in America and group B happens to be whites, then we come to the critical question of how to approach "whites" and "blacks." Given the genetic variation within any racial group, I think that the wrong approach is to assume a genetic basis as a first strategy to explain the difference. Rather, it is much more empirically valid to approach patterns of health disparities by focusing on external or environmental factors. To put it in plain language, it is fine to look at health disparities between any two groups—religious, gender, class, race, age, region of the country, et cetera—and ask why. But DNA should be the last place we look to try to explain those differences. Every molecular geneticist knows that there is far more genetic variation within what we call loosely African, European, and Asian continental ancestry than there is between these broad groupings.

TR: Yet the use of broad categories seems to be everywhere these days in medical research, from proposed U.S. Food and Drug Administration guidelines on clinical trials to reports on the success of various new drugs in a particular population. At the same time, most scientists have long maintained there is no biological basis for racial categories. How do you resolve these seemingly conflicting trends?
DUSTER: The contradiction is there, and it exists in the literature, sometimes inside a single article—and I must add, sometimes inside the brain of a single author. I think that the way to address the contradiction is to acknowledge that race is simultaneously a fluid, arbitrary, inter-

nally contradictory category in the way that it is used and that race is also a deeply embedded set of structural relationships between groups. Some people want to emphasize the arbitrariness of the biological category. But think of it this way: sub-Sahara Africans have the greatest genetic heterogeneity on the planet, yet when people from that part of the world travel outside of the continent, they are most likely to be treated as if they were genetically homogeneous. It is their treatment that results in patterned health disparities. The huge mistake is to then revert to the DNA, as if that were the source of the disparity.

TR: Howard University recently announced its plans to create a large database of the DNA of black Americans to better understand the diseases affecting this population. The effort, as you know, met both approval and strong criticism. What is your take on this?

DUSTER: One can possibly see some advantages, but one always has to weigh that against the downside. And in this rather volatile world of genetics and race and medicine, I think we need to be extremely careful heading down a path collecting genetic material on a particular racial group, because that very activity starts to send a message that race and genetics are much more interlinked than they actually are. My concern is with the symbolic ramifications: they're going to get the DNA of people of African descent as if somehow that database is going to be coherent, or more homogeneous. I'm sure that [the Howard researchers] are not that naïve. They are very thoughtful people who know genetics. I just think that when we learn that Howard University is collecting this database on black people, the question is, why are they stopping with black people? The implicit answer is that there is something special about the DNA of black people. The symbolic message is strong. And that's why I think we need to be very careful when we embark on this kind of work.

TR: Have the numerous advances in genomics over the last few years affected how you think about genetic differences and various population groups?

DUSTER: Yes, it has forced me to sharpen my critique of the reductionist impulse in biomedicine. The Human Genome Project and other developments have given a new imprimatur of scientific legitimacy to the "genetic" or "biological" attempt to explain complex social behaviors, from crime and violence to performance on IQ tests. When I wrote *Backdoor to Eugenics* at the beginning of the 1990s, I was simply warning about the implications of molecular genetics as a seductive explanation for complex behaviors. Up until about 1997, behavioral genetics and molecular genetics were almost completely separate. But now we are seeing a merger of interests and concerns in the two fields. And my critique is clearer, because I see that we are moving towards abandoning any attempt to "explain" behavior, except by using the imprimatur of molecular genetics.

TR: Your perspective as a sociologist is obviously very different from that of a geneticist. What are the dynamics between sociologists and geneticists?

DUSTER: Everyone thinks they're a sociologist. No one thinks they're a geneticist unless they are trained. Even my best-intentioned colleagues will say things like, "I hope you have on your research team someone who is a geneticist." And I wonder if I should respond, "I hope you have in your laboratory someone who is a sociologist." The assumption is, if you're going to be working in this area, you have to know genetics. But if you're a geneticist, you don't have to know anything about the sociological context of science. You're just supposed to do good genetics.

TR: Indeed, are geneticists and medical researchers generally attuned to the social and ethical implications of their work?

DUSTER: There are exceptions, but in general, with bench scientists, the answer is no. Many are oblivious of the extent to which their research is generated by social concerns. Few understand the social, economic, and political origins and ramifications of their research. So as long as the funds are flowing, these ethical, legal, and social issues are somebody else's concern. TR

Online Meeting

BY CORIE LOK

Using a webcam to chat in real time over the Internet is often a frustrating experience: there's nothing like jerky, unsynchronized movements to distract you. But a startup company out of Cornell University called SightSpeed has developed software that enables delay-free conversations over the Internet: you can see lip and eyebrow movements essentially as they happen.

Toby Berger, director of Cornell's digital signal compression and video encoding lab, started SightSpeed in 2001 to commercialize technology that speeds up the encoding and decoding needed to send and receive video over the Internet. With exclusive licenses from Cornell and more than $1 million in venture capital, mainly from the Roda Group of Berkeley, CA, the company released its software this past winter and has sold it to two corporate customers; Berger says three more deals are in the works.

In addition, more than 43,000 individuals have downloaded the software, which was offered free on the company's Web site for the first six months after its release. With an off-the-shelf webcam and a high-speed Internet connection, a person can see and talk online with other SightSpeed registrants.

With more voice and video communication being done over the Internet and Web conferencing predicted to be a $1.1 billion industry by 2007, SightSpeed could be in a prime position to cash in. "There's a need for good-quality, fast, lightweight videoconferencing technology for the desktop," says Robert Mahowald, a research manager with IDC, a Framingham, MA, market research firm. "There aren't many good products out there. SightSpeed's might be better."

SIGHTSPEED

HEADQUARTERS: Berkeley, CA

UNIVERSITY: Cornell

INVESTMENT RAISED: $1 million

LEAD INVESTORS: Roda Group

KEY FOUNDERS: Toby Berger, Aron Rosenberg, Brad Treat

SightSpeed says its video runs at 30 frames per second, the same rate as TV and faster than film. That's a huge improvement over other forms of Web-based videoconferencing or messaging, which typically go no higher than 20 frames per second, resulting in that off-putting jerkiness. Berger uses algorithms that require less computation, speeding up the video compression process. The technology mimics how the eye works, encoding data that the eye would normally pick up and throwing away what it would miss anyway. "We're being smarter about what data is sent, based on human perception," says Brad Treat, the company's CEO.

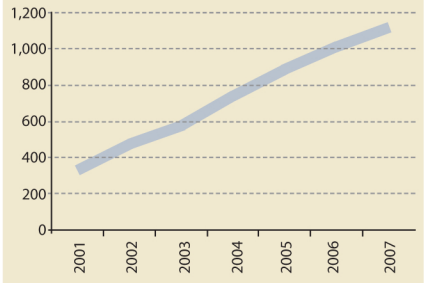
"The video quality is extraordinary," says Marc Beattie of Wainhouse Research, a Brookline, MA-based market research firm. He used SightSpeed's software to watch SightSpeed employees online while talking with them over the telephone. "The audio and video were synched up. It's a neat little trick."

But going after business users of Web-based conferencing—the dominant market for remote conferencing—won't be easy. For one thing, SightSpeed's technology doesn't conform to existing videoconferencing standards, says Beattie. A business will only be able to videoconference with those also using SightSpeed, and many corporations may be reluctant to rely on a small, young company. Berger, however, is undaunted. He says SightSpeed is leaving the standards behind with its superior technology. "If we were compliant with the standards, we wouldn't have these advantages [of shorter delays]," says Berger.

In any case, it may be the average Web user who is most attracted to SightSpeed's smooth video. Business use of remote conferencing is heavily geared toward viewing data, such as Powerpoint presentations, rather than viewing video images of those speaking. "The gee-whiz factor is much more compelling for consumers," says Mahowald.

That still leaves one more challenge: SightSpeed may have to go up against the industry's 800-pound gorilla. Microsoft recently launched Live Meeting, a data- and application-sharing program for businesses. But Microsoft hasn't yet incorporated online voice or video into its product, potentially giving SightSpeed a leg up with those Web users hungry for better videoconferencing. And depending on how you view it, big players like Microsoft moving into the area of real-time communication on the Internet present either competition or great market opportunities for SightSpeed.

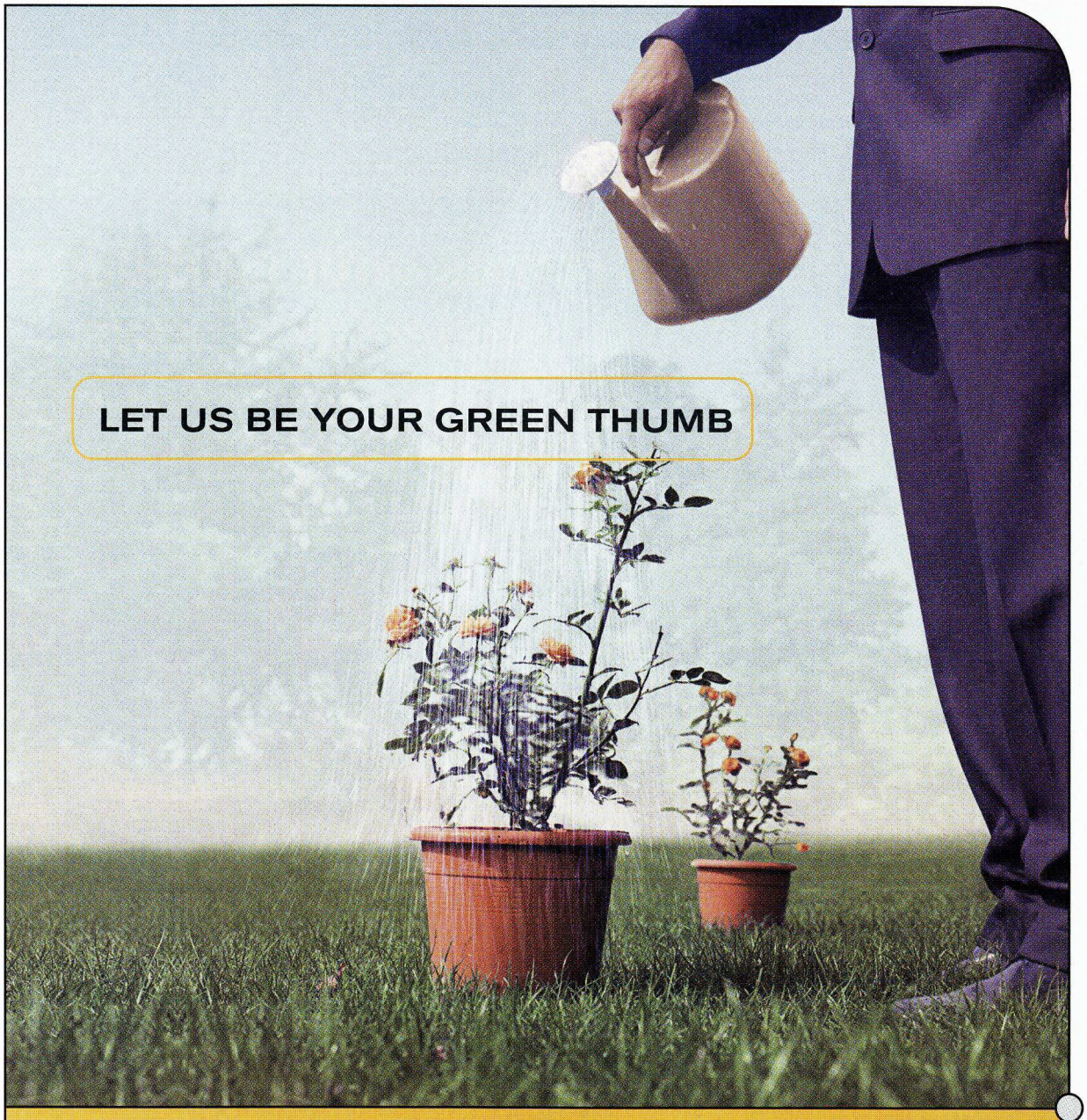
WEB CONFERENCING MARKET



OTHERS IN ONLINE VIDEO COMMUNICATION

COMPANY	TECHNOLOGY
Yahoo! (Sunnyvale, CA)	Video instant messaging at up to 20 frames per second
Microsoft (Redmond, WA)	MSN Messenger and Windows XP Messenger, both of which are webcam-enabled
WebEx (San Jose, CA)	Web conferencing package for private business networks
Apple Computer (Cupertino, CA)	Personal videoconferencing using software and webcams

SOURCE: IDC 2003 (CHART)



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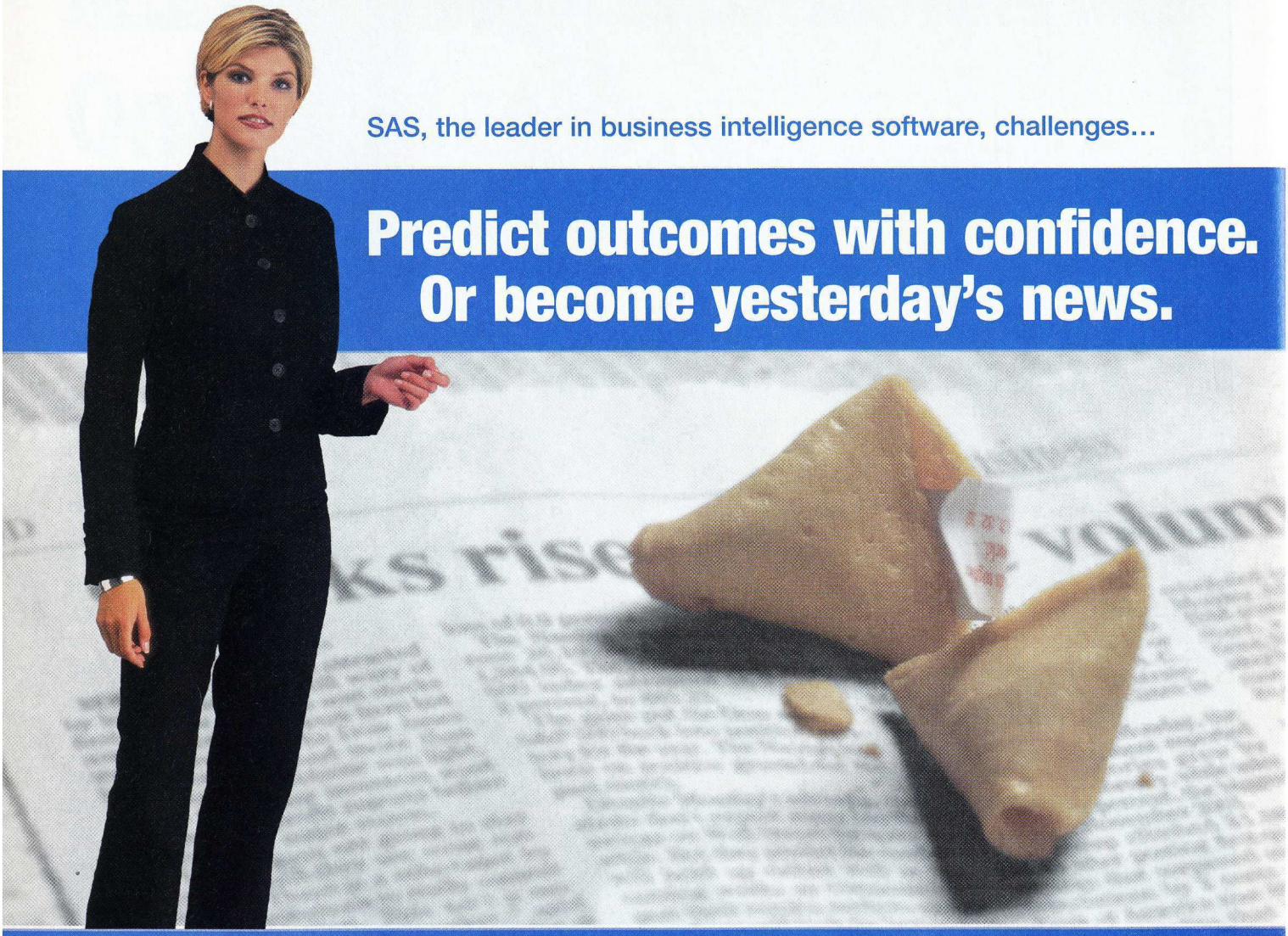

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Bomb Scanners

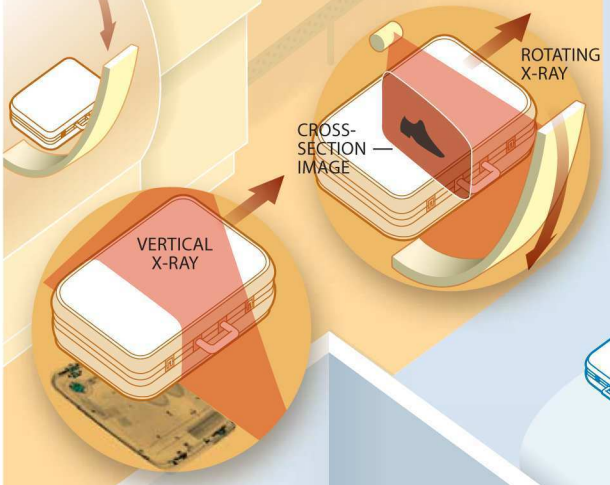
As of December 31, 2002, every bag checked onto a U.S. flight must first be run through a bomb detector. More than 1,060 explosive-detection systems and 5,300 trace detectors are currently used for luggage. These systems employ x-rays and computer tomography to scan for suspicious shapes and object densities. But the U.S. Transportation Security Administration is considering alternative devices—including some for passengers—that will identify the chemical signatures of explosives. Two technologies have successfully passed early tests. **TEXT AND ART BY 5W INFOGRAPHIC**

NOW...

X-RAYS AND CT SCANS

The current explosive-detection systems use a combination of x-rays and computer tomography (CT).

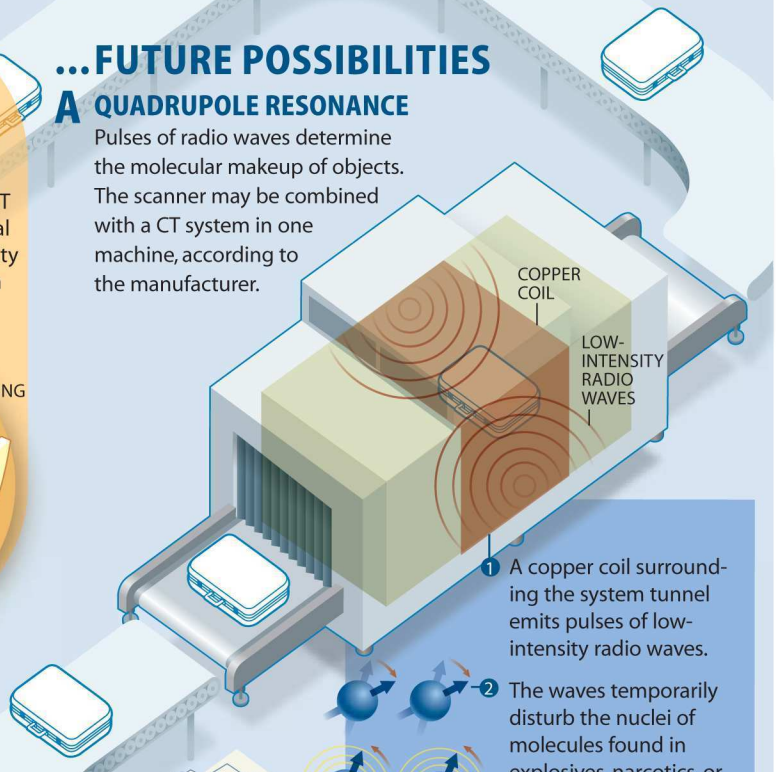
1. The vertical beams of an x-ray scanner produce 2-D images that reveal suspicious shapes.
2. The rotating x-ray beams of a CT scanner produce cross-sectional slices; the size, shape, and density of an object are compared with those of known explosives.



...FUTURE POSSIBILITIES

A QUADRUPOLE RESONANCE

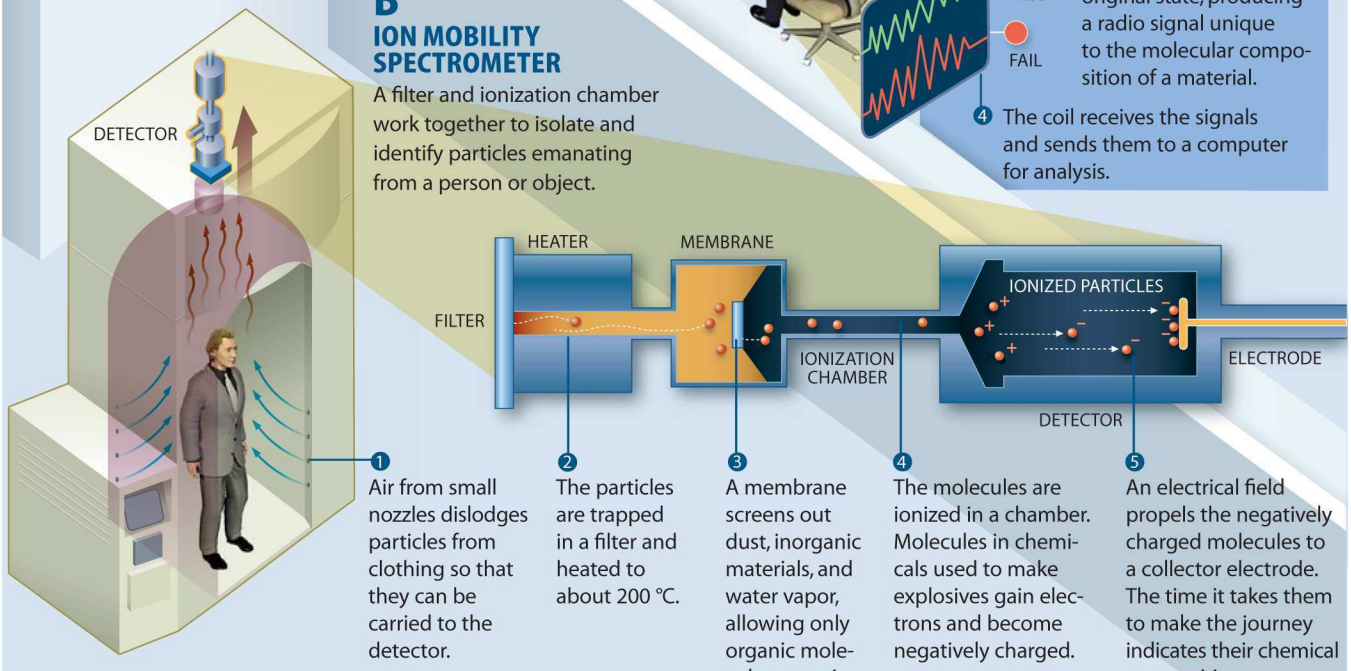
Pulses of radio waves determine the molecular makeup of objects. The scanner may be combined with a CT system in one machine, according to the manufacturer.



1. A copper coil surrounding the system tunnel emits pulses of low-intensity radio waves.
2. The waves temporarily disturb the nuclei of molecules found in explosives, narcotics, or other harmful materials.
3. In between pulses, the nuclei return to their original state, producing a radio signal unique to the molecular composition of a material.
4. The coil receives the signals and sends them to a computer for analysis.

B ION MOBILITY SPECTROMETER

A filter and ionization chamber work together to isolate and identify particles emanating from a person or object.



1. Air from small nozzles dislodges particles from clothing so that they can be carried to the detector.
2. The particles are trapped in a filter and heated to about 200 °C.
3. A membrane screens out dust, inorganic materials, and water vapor, allowing only organic molecules to go in.
4. The molecules are ionized in a chamber. Molecules in chemicals used to make explosives gain electrons and become negatively charged.
5. An electrical field propels the negatively charged molecules to a collector electrode. The time it takes them to make the journey indicates their chemical composition.

SOURCES: INVISION TECHNOLOGIES, GE INTERLOGIX, U.S. TRANSPORTATION SECURITY ADMINISTRATION

Stop! ID Thief!

MORE THAN THREE MILLION PEOPLE IN THE United States were the victims of identity-theft-related fraud in the past year, according to a recent survey by the Federal Trade Commission. These people have had accounts opened in their names by scam artists, they've had their names given to the police by crooks stopped for various infractions, and they've had their homes sold out from underneath them. Damages to these victims average more than $10,000 per theft.

Grim as these statistics may be, the growing amount of credit card fraud is even worse: more than five million people had sham transactions dropped onto their credit card statements last year, and more than a million others have had non-credit-card accounts misused, including savings and checking accounts. Fortunately, you can protect yourself using a combination of ingenuity and tech savvy.

The whole foundation of the credit system is fundamentally insecure. A credit card number is really nothing more than a password—a password that's not even secret, because you need to share it in order to use it. Just about the only way that you can detect misuse is to watch your accounts for unauthorized activity.

Keeping such a watchful eye is a lot easier now than it used to be. Credit card companies allow you to view your transactions on secure Web sites. For many people, however, even the few minutes it takes to deal with these sites is a big disincentive. But personal-finance programs like Quicken or Money streamline this process. I use Quicken, which automatically downloads new transactions from my credit cards, bank accounts, and investments with a single mouse click. To use this feature, you first store all of your account numbers and passwords in the program's "PIN Vault." There's no need for you to memorize all those digits: the information is kept encrypted under a master pass phrase.

Getting Quicken set up is only half the battle, of course. You also have to manually review your downloaded transactions every few days to find out if somebody is using your credit card without your authorization. Banks and credit card companies are always looking for fraud as well, but they frequently don't catch it until it is too late. You can nip the problem in the bud by calling up your credit card company and asking for a new account number at the first sign of fraud.

Credit card technology is fundamentally insecure. You can protect yourself by using ingenuity and tech savvy.

Another source of fraud is those "convenience checks" that the card companies send in the mail. Crooks steal them out of your mailbox and go on their own personal spending sprees. Protect yourself by calling up your credit card company and asking them to stop sending the checks. A locked mailbox is a good idea, too. And though it might sound extreme, buy a good crosscut shredder for your receipts; identity thieves have posed as homeless people, rummaging through trash, looking for bank statements and other sources of personal information.

While you have the credit card company on the phone, have them put a password on your account. This replaces your "mother's maiden name" and is much more secure. Finally, ask the credit card companies to stop sharing your personal information with other businesses. This will stop some of the junk mail coming into your house, including those "pre-approved" credit card offers, which are a primary source of identity theft.

Identity theft is generally hard to prevent because it involves new accounts that crooks open in your name, rather than old accounts for which you have the account numbers. Again, the best way to protect yourself is by getting more information. Both Equifax and TransUnion offer credit-monitoring services. For a monthly fee they'll watch your credit file and let you know whenever a new account is opened in your name, or when one of your creditors reports that you're late to make a payment on an already opened account. To notify you, they send an e-mail message that asks you to log in to a password-protected Web site. If you see a suspicious account, you can call up the bank, report the fraud, and try to have the account shut down.

The Equifax service costs $4.95 per month if you want alerts sent within seven days of suspicious activity, $9.95 per month if you want alerts sent within 24 hours. TransUnion charges $10.95 for three months and provides notification within a week. Of course, it is the poor security practices and aggressive sale of credit reports that are largely responsible for the identity theft epidemic in the first place. Still, my advice is to swallow your indignation and sign up for these services.

Finally, don't click on links in e-mail messages from unknown senders. Thieves are sending out messages that look as if they come from PayPal or eBay, then capturing the usernames and passwords of people who attempt to log in to fake Web pages. Avoid this scam by typing the companies' Web addresses directly into your browser rather than clicking on links.

Perils abound on the electronic frontier. Taking a few smart precautions will ensure that you don't have people copping your identity to plunder your bank account and sully your reputation.

Simson Garfinkel is an incurable gadgeteer, an entrepreneur, and the author of 12 books on information technology and its impact.

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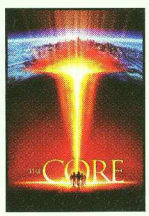

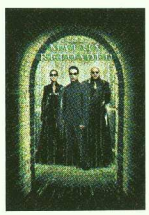

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A 1959 sea test of a prototype hovercraft.

Hovercrafter

Plans for an amphibious vehicle languished in classified files before finally taking off. BY LISA SCANLON

Hundreds of thousands of people ride them every year, from tourists visiting the British Isles to postal workers delivering goods to remote Alaskan villages. British engineer Christopher Cockerell patented the hovercraft, which travels on a cushion of air over land and water, in 1955—but he struggled to arouse any interest in his device. It wasn't until his prototype crossed the English Channel in 1959 that it really took off.

Born in 1910 in Cambridge, England, Cockerell showed an early aptitude for engineering, motorizing his mother's sewing machine. His father, an art museum curator, wasn't impressed; he commented that his son was "no better than a garage hand." In spite of this, Cockerell studied engineering at the University of Cambridge and in 1935 joined Marconi's Wireless Telegraph Company, where he received 36 patents, most related to radio navigation aids for airplanes.

When Cockerell and his wife came into a small inheritance in 1950, he took a brief hiatus from inventing, leaving Marconi to run a boatyard. There, Cockerell began investigating ways to use air to cut down on friction between a boat's hull and the water. Using powerful fans, he reasoned, he could create a cushion of air that would enable a craft to hover over the water, and even over the ground. After early experiments with empty tin cans, a vacuum cleaner, and a pair of kitchen scales, Cockerell had a local boat builder construct him a 60-centimeter-long working model. He patented the device and dubbed it the "hovercraft."

By 1957, Cockerell had demonstrated his device to British military officials. They weren't interested in developing it but still classified it as secret, so Cockerell couldn't pitch it elsewhere for more than a year. After the hovercraft was declassified in 1958, he finally convinced the National Research Development Corporation, a government-funded agency, to develop it for commercial use.

The first hovercraft skimmed across the British Channel in the spring of 1959, and Cockerell and his "British flying saucer" became celebrities. By 1962, regular hovercraft passenger services were popping up around the United Kingdom. Still, Cockerell felt he was never adequately compensated for his ideas; in a 1996 interview with the London *Times*, he commented on the low salary he received while developing the hovercraft. On June 1, 1999, Cockerell died—exactly 40 years after the hovercraft was first launched. TR

COURTESY OF SAUNDERS ROE AND THE BRITISH HOVERCRAFT ARCHIVES

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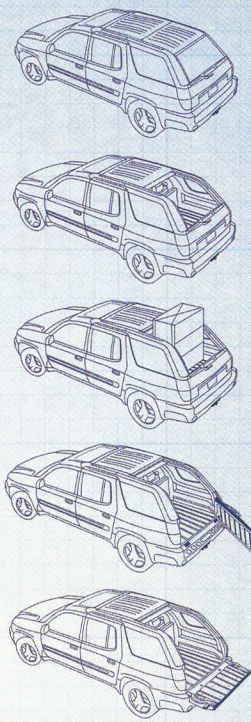

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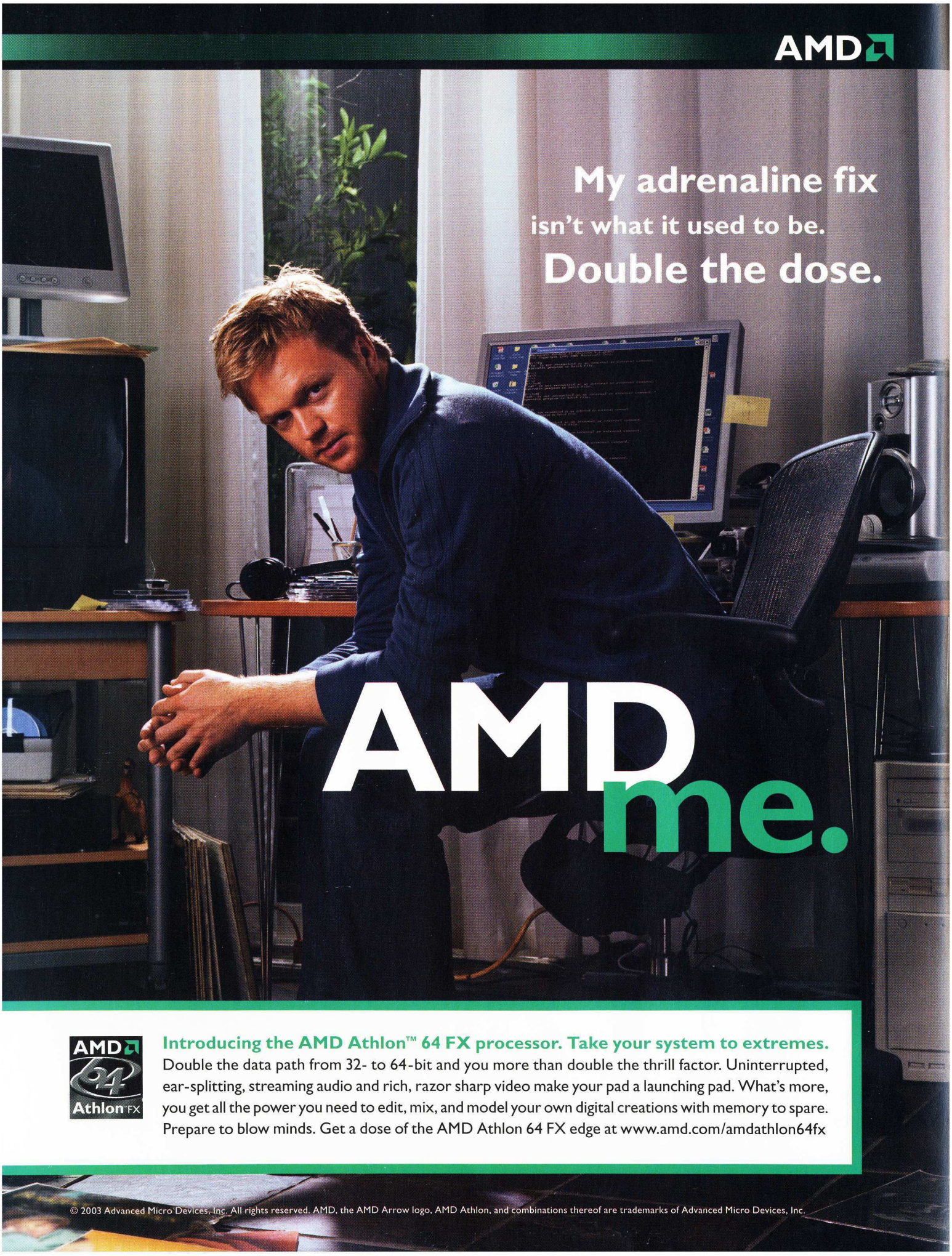
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